Changes in Lake Sturgeon (*Acipenser fulvescens*) Habitat in the South Saskatchewan River under Regional Climate Change

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Abstract

Climate change effects have been documented in the Canadian Prairie Provinces. Temperature is predicted to continue to increase, and precipitation patterns are changing. As a result, river flow is anticipated to diminish. The South Saskatchewan River (SSR) provides vital habitat to lake sturgeon. Lake sturgeon are currently endangered or threatened across most of their native range, prompting provincial governments to develop management strategies. As lake sturgeon habitat is dependent on flow, understanding climate change impacts on flow conditions in the SSR will be an important component of their long-term management strategy for lake sturgeon. We have developed empirical models based on regional climate variables (temperature and precipitation) to predict in-stream flow. These models were developed using general linear modeling and Akaikes Information Criterion (AIC). Future in-stream flow was predicted by extracting key variables from 5 different GCM's and inserting the variables into the predictive flow models. These future flow scenarios were coupled with habitat suitability indices to assess changes in sturgeon habitat. Habitat suitability indices have been developed by the Water Security Agency and Department of Fisheries and Oceans Canada. Flow scenarios predict a decrease in the habitat of most life stages (spawning, juvenile, adult and subadult), but an increase in fry habitat. These models will represent a novel advancement for sturgeon management in Western Canada.

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List of Abbreviations

SSRB: South Saskatchewan River Basin

SSR: South Saskatchewan River

DU2: Designatable unit 2

VIF: Variance inflation factor

AIC: Akaike's information criterion

GCM: Global climate model

RCM: Regional climate model

MLR: Multiple linear regression

CMS: Cubic meters per second

MSE: Mean square error

SRES: Special report on emissions scenario

IPCC: Intergovernmental panel on climate change

WSA: Watershed security agency

1.0 Introduction

1.1 *Lake Sturgeon*

In Canada there are approximately 200 species of freshwater fish that occupy rivers for some or all of their life (Scott and Crossman 1973). Seasonal precipitation (particularly spring precipitation and runoff) is an important factor for maintaining riverine fish habitat because water level and temperature initiating spawning. However, shifts in the timing and the form of precipitation (i.e., rain versus snow) brought on by climate change are expected to impact river ecosystems through changes in water levels, flow regimes, and temperature profiles (Wilby and Harris 2006; Vörösmarty et al. 2000; Isaak and others 2014; Ashraf Vaghefi et al. 2014). This will, in turn, alter the structure and availability of fish habitat (Barnett, Adam, and Lettenmaier 2005; Wrona et al. 2006; Eaton and Scheller 1996; Lane et al. 2014). Feeding, spawning, and overwintering habitat for fish are all predicted to be affected by climate change (Morrison, Quick, and Foreman 2002; De Stasio et al. 1996). As a long lived fish species (80+ years), sturgeon have adapted to a life strategy that favours rapid somatic growth in juveniles (Beamish et al. 1996), which results in delayed sexual maturity (12-15 years for males and 20-25 for females) (Bruch and Binkowski 2002). This, combined with protracted spawning (once every 4-9 years in females, once every 1-3 years in males) makes lake sturgeon particularly susceptible to modifications in habitat, like those being brought on by changes in climate (Harkness and Dymond 1961; Auer 1996). They are physiologically unable to rapidly adapt due to their long generation times (Bradshaw and Holzapfel 2006). It is for this reason that larger, longer lived species of fish, such as lake sturgeon

(*Acipenser fulvescens*) are expected to be heavily impacted by climate change. This inability to adapt has already left lake sturgeon a threatened or endangered species throughout its native range. They are a high priority species for protection, already being listed by The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) as endangered (Government of Canada 2009b). As such, long-term conservation strategies that consider the changing climate must be developed in order to protect lake sturgeon populations.

1.11 *Biology and Ecology*

Lake sturgeon is a torpedo shaped, cartilaginous freshwater fish. They lack scales, instead possess five rows of bony scutes that run laterally along the length of their body (Harkness and Dymond 1961). These scutes are used as protection from predators, and therefore are rougher and sharper in juvenile fish. They wear down in larger, older specimens, likely due to the trade-off between the increased energy expenditures needed for travelling with friction inducing armour versus the need for protection from aquatic predators (Peterson, Vecsei, and Jennings 2007). Older fish are larger in size, and have outgrown predators and the need for armour.

1.111 *Diet*

Lake sturgeon have arrow shaped rostrums with four barbels near the tip, and a protrusible jaw making it possible for this benthivourous fish to project its mouth downward when feeding (Vecsei and Peterson 2005). Lake sturgeon follow a benthic generalist feeding strategy, feeding primarily on amphipod and chironomid larvae at age-0, progressing to oligocheates, aquatic insects (nymphs of ephemeroptera and trichoptera larvae), molluscs and fish eggs as juvenile (70-80 cm total length) (Harkness and Dymond 1961; Peterson, Vecsei, and Jennings 2007; Randall, Fisheries, and Oceans 2008).

1.112 *Life cycle*

When water temperatures reach 10-15°C lake sturgeon spawn. This usually happens between mid-April and June in shallow, fast moving water with a cobble or gravel substrate (Priegel et al. 1974; LaHaye et al. 1992). Lake sturgeon eggs hatch 5-14 days after fertilization depending on water temperatures (Kempinger 1988; Cleator et al. 2010). After hatching, the young lake sturgeon are pelagic and negatively phototactic, hiding in the interstitial spaces in the cobble substrate where they are spawned (Y. L. Wang, Binkowski, and Doroshov 1985; Harkness and Dymond 1961). The age-0 lake sturgeon emerge from their benthic habitat at night within 13-19 days of hatching, and are carried kilometers downstream by the rivers current (Cleator et al. 2010; Peterson, Vecsei, and Jennings 2007; Kempinger 1988).

These early stages of the life cycle see the fish growing rapidly from approximately 1.7 cm at emergence to around 11-20 cm total length by the end of their first summer (Cleator et al. 2010). In the juvenile stage of development, lake sturgeon grow more rapidly in length rather than in weight, but after 5-15 years of age the fish tend to grow more in weight than in length (Cleator et al. 2010). Like adults, diets of juvenile lake sturgeon consists largely of benthic invertebrates (Chiasson, Noakes, and Beamish 1997; Wallus and Simon 2008).

Adult lake sturgeon are defined by the formation of all adult features, including gonads (Peterson, Vecsei, and Jennings 2007). Adult males are typically smaller than females, reaching between 100-185 cm total length and 11-30 kg. Females being the larger of the two sexes, have been known to span 130-215 cm total length and 25-100 kg in mass, although fish on the larger end of this scale are presently very rare (Beamish et al. 1996; Harkness and Dymond 1961).

1.12 *Habitat*

Habitat selection for lake sturgeon changes seasonally, as well as being dependant on life stage. Mature lake sturgeon are capable of long migrations in order to reach suitable spawning grounds (80 km or more). This typically occurs mid-April to early June (Cleator et al. 2010). Spawning occurs in shallow waters (0.1-2 meters) over cobble or gravel substrate, when water temperatures reach 10-15°C. A current velocity of 0.5-1.3 $m \cdot s^{-1}$ is preferred (Priegel et al. 1974; LaHaye et al. 1992). Eggs adhere to the substrate, and are oxygenated by the moving water. Upon hatching, larval sturgeon remain in the cobble substrate to avoid predation (Peterson, Vecsei, and Jennings 2007; Harkness and Dymond 1961). Year old juveniles are thought to congregate in lower velocity areas (0.25-0.5 $m \cdot s^{-1}$) such as the mouths and adjacent bays of shallow rivers during the summer and fall (Cleator et al. 2010; Peterson, Vecsei, and Jennings 2007; Priegel et al. 1974). Overwintering occurs in the deeper pools (>2 m) of their natal stream (Peterson, Vecsei, and Jennings 2007; Priegel et al. 1974). After their first year, juvenile sturgeon are thought to seek out the same habitat as adult sturgeon (Priegel et al. 1974).

Mature lake sturgeon are most often observed during spawning, but are known to occupy deep pools of water the remainder of the year (less than nine meters deep in the winter, more than nine meters deep in the summer) (Harkness and Dymond 1961; Priegel et al. 1974). Habitat selection of non-spawning adults emphasizes food availability rather than substrate type (Harkness and Dymond 1961).

1.13 *Distribution*

Lake sturgeon have historically populated many river basins in North America, including Hudson Bay, St. Lawrence, Great Lakes and Mississippi (Fig.1.1). However, due to anthropogenic disturbances (habitat fragmentation by dams, over fishing, and pollution), lake sturgeon no longer populate their entire historical range (Auer 1996; Peterson, Vecsei, and Jennings 2007; Rochard, Castelnaud, and Lepage 1990). In most areas where lake sturgeon are still present, their populations are depressed below historic levels (Peterson, Vecsei, and Jennings 2007).

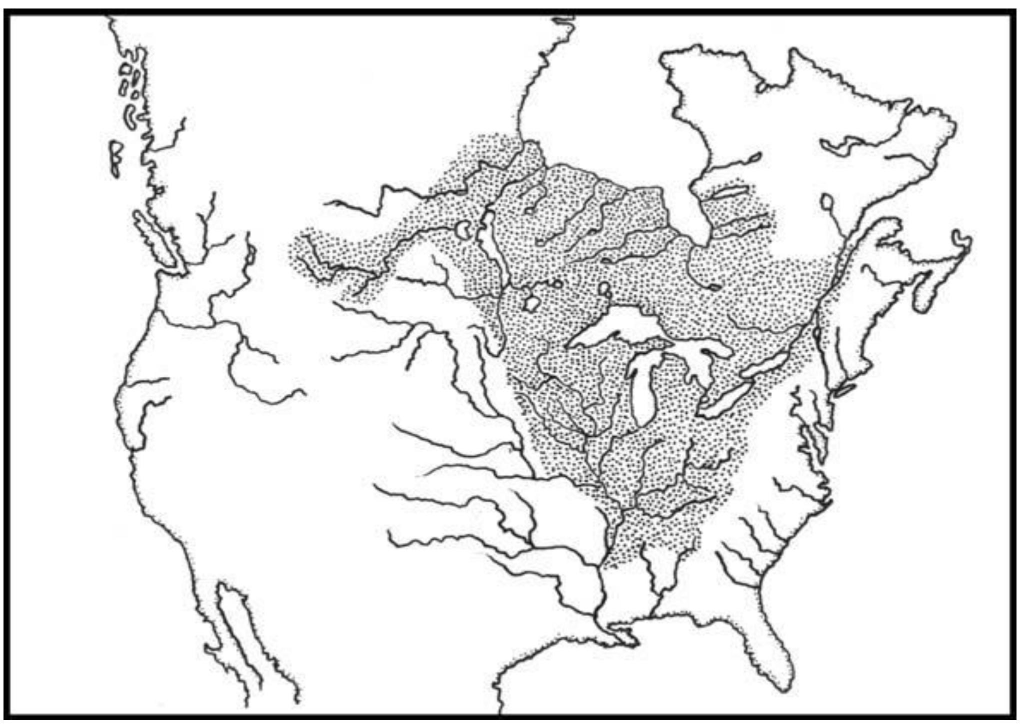

Figure 1.1. Historical distribution of lake sturgeon (*Acipenser fulvescens*) in North America showing the South Saskatchewan River Basin to be the primary habitat for lake sturgeon in its western-most range. (From Peterson et al. 2006)

In Western Canada, lake sturgeon is found primarily in the South Saskatchewan River Basin (SSRB). Historically, lake sturgeon have populated all of the tributaries within the SSRB. Presently though, they are primarily located in the lower portions of the Oldman, Red Deer, and Bow Rivers, as well as the South Saskatchewan River (SSR) upstream from Gardiner Dam (Cleator et al. 2010). Within the SSR, lake sturgeon are believed to have been extirpated from between Gardiner Dam and Saskatoon, and only a small number of fish have been reported downstream from Saskatoon (Cleator et al. 2010). Most reports of lake sturgeon in the Saskatchewan part of the SSR come from the Leader area (Cleator et al. 2010).

1.14 *Status*

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) has divided the current range of lake sturgeon into eight designatable units (DU). Five of these eight units have populations of lake sturgeon [including the Saskatchewan River population (DU2)] that have been classified as endangered (Government of Canada 2009b). The population that is found in the SSR was most recently reviewed by COSEWIC in 2007, and was found to be endangered. While currently being reviewed for inclusion on Schedule 1 in the Species at Risk Act (SARA), lake sturgeon is not currently afforded protection under the SARA.

1.2 *Study Area*

The Saskatchewan River population of lake sturgeon is of special concern not only because this population has been classified as endangered (Government of Canada

2009b), but also because the SSR has been identified by the World Wildlife Federation (WWF 2013) as the most threatened river in Canada in terms of environmental flows.

Source waters of the SSR flow from the eastern slopes of the Rocky Mountains. The SSR is part of the larger Saskatchewan-Nelson River Watershed. It has three major tributaries, the Bow, the Oldman, and the Red Deer Rivers, all of which converge near the Alberta/Saskatchewan border to form the SSR (Figure 1.2). The SSR passes through a variety of eco-regions starting from the northern continental divide in the Rocky Mountains, passing through aspen parkland, mixed grassland, and finally ending in the boreal transition zone (Lac and Colan 2004). The majority of the basin is dominated by the prairie ecozone, typified by grasslands, which are flat or only gently rolling. Climate in the basin ranges from semi-arid, to humid continental (Lac and Colan 2004; Van der Kamp, Hayashi, and Gallen 2003). Summers are short and hot, with long cold winters.

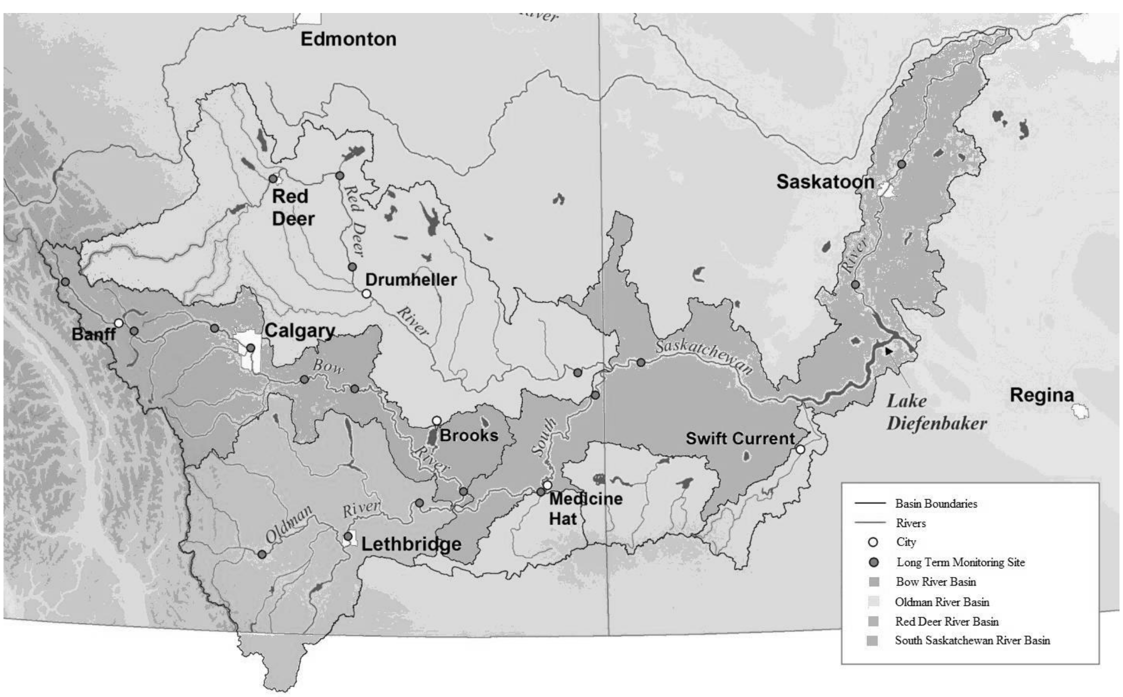

Figure 1.2. Map of the South Saskatchewan River Basin, including all relevant sub-basins.

The majority of precipitation occurs in the winter (Lac and Colan 2004). Substrate in this river varies from rocky boulders, to sand, mud and clay along the length of the river (Culp and Davies 1982; Lehmkuhl 1972).

Flows in the SSR are under threat, with the river facing many challenges (Wheater and Gober 2013). This is for a variety of reasons. The SSR and its tributaries already contain thirteen large hydropower dams as well as hundreds of smaller dams, changing the hydrology of this system. Dams create reservoirs, making upstream of the dam more similar to a lacustrine environment rather than riverine. Downstream flow has also changed as a result of the damming. Downstream flows will not necessarily be dictated by seasons or ecological needs, instead changing based on anthropogenic needs, ie. reservoir height. In some parts of the watershed, water allocations total 70% of the river's natural flow, the highest for any Canadian river, compounding the stress on an already fragmented system (L. Wang, Fang, and Hipel 2008; WWF 2013). Source glaciers have also been shrinking (Comeau, Pietroniro, and Demuth 2009; WWF 2013). As melt water from the Rocky Mountains account for 87% of flow at the South Saskatchewan's River mouth, these are concerns over the long-term stability of the SSR (Schindler 2001).

1.3 *Climate Change*

Many regions worldwide, including the semi-arid regions of the Western Prairie Provinces, are experiencing climate change. In the last century, temperatures in the SSRB have risen 1-4°C, and precipitation patterns are changing (Schindler and Donahue 2006; Töyrä, Pietroniro, and Bonsal 2005). Changes in regional climate have been shown to influence river discharge (Rood et al. 2008; Schindler 2001; Lane et al. 2014). The warming climate is causing an earlier spring run-off and peak flow (Rood et al. 2008). This can directly affect sturgeon spawning, as a shift in peak flows to earlier in the season will alter the timing of when water will reach the correct temperature. It can also influence current velocities preferred by spawning sturgeon, as well as those needed to oxygenate sturgeon eggs.

Snow packs currently contribute the majority of the flow in the SSR (Cohen 1991). However, an increase in the mean annual air temperature is reducing the amount of precipitation falling as snow and increasing the amount of precipitation falling as rain. This shift in precipitation patterns has reduced spring melt water from snowpack. In turn, many years have experienced a decline in spring and summer flow, while fall and winter flow down the SSR has increased (Rood et al. 2008; Lapp et al. 2005). Future snowmelt scenarios for this basin predict as much as a fifty percent reduction in contributions (Lapp et al. 2005), which will drastically decrease future flows in every season. It is acknowledged though that precipitation predictions vary as they are inherently difficult to model (Mearns et al. 2012; Asong, Khaliq, and Wheater 2014). As one of the only rivers in DU2 with remaining populations of lake sturgeon, the long-term stability of this system will directly influence the future viability of this species.

A reduction in flow will have considerable impact on sturgeon populations by altering the availability and depth of pools used for overwintering, feeding, as well as access to spawning habitat (Bunn and Arthington 2002). A change in flow will also alter habitat suitability through changes in the pattern of sedimentation and substrate type (Bunn and Arthington 2002). As flows decrease in the spring, cobble can be covered by silt, which would decrease potential spawning habitat. It can also affect the abundance of sturgeon prey. As water temperatures and flow regimes change, important abiotic cues for sturgeon prey (like aquatic invertebrates) can be disturbed, possibly causing a decrease in food availability for sturgeon (Auer 1996).

1.4 *Objectives*

I will investigate the relationships between river flow and two regional climate vectors, temperature and precipitation. My primary objective is to develop empirical models that will predict river discharge on a monthly basis. After developing the set of predictive monthly flow models, key climate variables will be extracted from online global climate models. These values will be inserted into the monthly flow models in order to obtain a set of monthly future flow projections. My second objective will be to pair these future flow scenarios with lake sturgeon habitat suitability indices. This will allow a better understanding of the potential for climate change to impact lake sturgeon habitat in the SSR. To date, studies have attempted to link climate changes with changes in fish habitat based on water temperature (Mohseni, Stefan, and Eaton 2003; Rahel, Keleher, and Anderson 1996; Eaton and Scheller 1996). Models that tie in climate and flow-based fish habitat are largely absent from literature. A study of this kind would have broad applications in many semi-arid and arid regions worldwide.

2.0 Building Flow Models

2.1 *Study Site*

Focal sites for this study were chosen based on specific criteria. First, a site was needed that had multiple upstream locations with long-term precipitation and temperature datasets. The second criterion was finding a site that had naturalized flow. Finally, the focal site had to contain well-documented lake sturgeon habitat. The first two criteria were met at a site just outside of Leader Saskatchewan, which is located on the SSR. It is just downstream of the Alberta/Saskatchewan border after all major tributaries have joined the main stem of the South Saskatchewan River. This is the only location in Saskatchewan for which naturalized flows had been developed therefore this was used as a primary study site. The naturalized flow data at this site was used to develop the subsequent predictive flow models.

However, this site did not have corresponding lake sturgeon habitat information available, so a secondary site was also needed. Habitat data was available at Clarkboro ferry, a site downstream from the primary study site. The predictive flow models (which were developed using naturalised flow data from Leader) were applied to habitat information collected from this secondary site at Clarkboro ferry (Fig. 2.1). While it would have been ideal to have only one focal site, no single site on the SSR fit all of the criteria; hence the best two sites were used.

2.11 *Blocked Experimental Design*

Using a blocked design, the upstream portion of the South Saskatchewan River

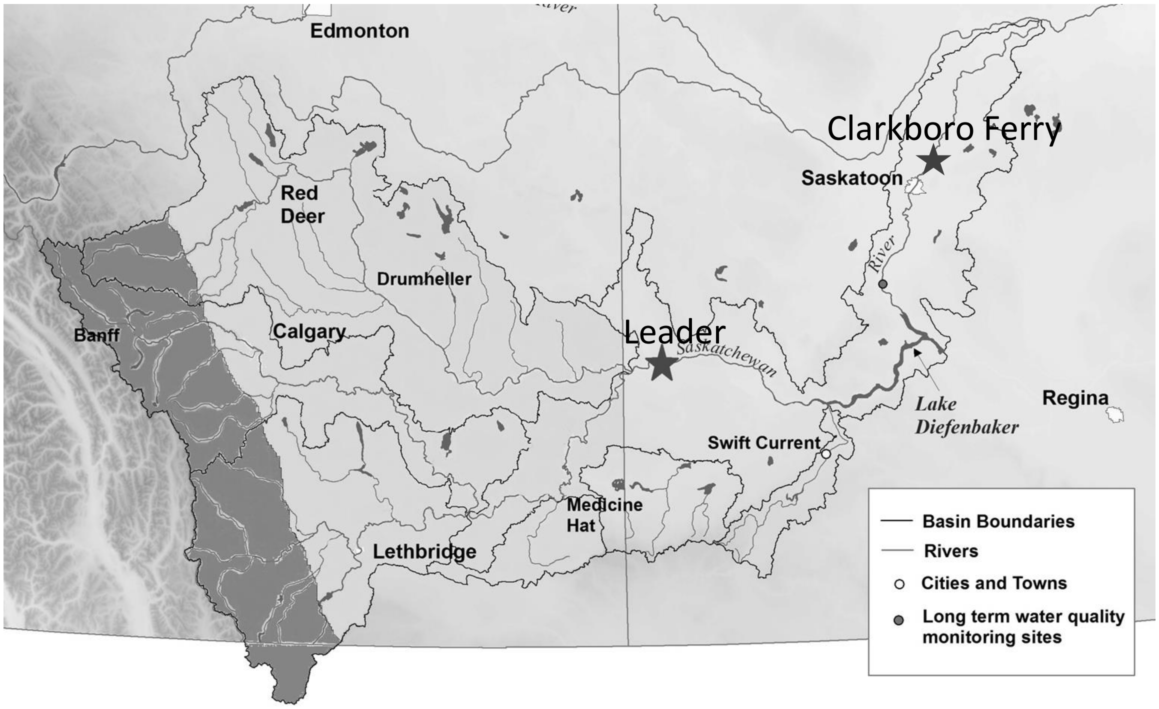

Figure 2.1. Map of the SSRB with Leader SK, and Clarkboro Ferry SK indicated by stars. These were the two primary study sites. The upstream portion (to the left of Leader SK) is where the climate data was collected. The darker, more upstream portion represents the mountain region, and eastern shaded region represents the plains region. The basin region is a combination of both mountain and plains regions.

Basin was split into two regions, mountains and plains (Neter, Wasserman, and Kutner 1996). Each of the regions were further subdivided, with the mountains having 5 blocks, and the plains region having 10 blocks (Addelman 1969). This reflects the different geographies of the basin. The plains region had approximately twice the area of the mountain region. The placement of these blocks followed a grid pattern. This was to avoid giving any one geographic area within a region more representation than other areas (Addelman 1969). In each block, data was collected from one station which was used as a representation of climate in that regional block. Each station was chosen from the many potential climate stations found in each block. Selection was based on length and completeness of the data sets needed for this study (Table 2.1).

Table 2.1. Location names, identification numbers, coordinates, years, as well as data type and units for which data were collected. Elevation is in meters

Station	Data	Unit	Northing			Westing			Elevation	Start	End	ID
Highway 41	Flow	m^3/s	50	44	15	110	5	45		1967	1993	05AK001
Lemsford	Flow	m^3/s	51	1	20	109	7	30		1958	1970	05HB001
Medicine Hat	Precip	mm	50	1	11.14	110	43	9.71	717	1886	2007	3034480
	Temp	°C	50	1	11.14	110	43	9.71	717	1895	2008	3034480
Banff	Precip	mm	51	11	52.41	115	32	52.34	1397	1894	2007	3050519
	Temp	°C	51	11	52.41	115	32	52.34	1397	1895	2008	3050519
Calgary	Precip	mm	51	7	20.34	114	0	51.79	1084	1885	2008	3031093
	Temp	°C	51	7	20.34	114	0	51.79	1084	1895	2008	3031093
Gleichen	Precip	mm	50	52	45.36	113	3	5.53	905	1903	2006	3032800
	Temp	°C	50	52	45.36	113	3	5.53	905	1903	2006	3032800
Lake Louise	Precip	mm	51	26	0	116	13	0	1,524	1919	2007	3053760
	Temp	°C	51	26	0	116	13	0	1,524	1919	2007	3053760
Carway	Precip	mm	49	0	8.29	113	22	37.07	1354	1915	2007	3031400
	Temp	°C	49	0	8.29	113	22	37.07	1359	1914	2007	3031400
Crowsnest	Precip	mm	49	37	52.92	114	28	46.39	1303	1913	2007	3051R4R
Coleman	Temp	°C	49	39	0	114	30	0	1341.1	1961	1997	3051725
Lethbridge	Precip	mm	49	41	55.54	112	46	58.65	929	1902	2007	3033880
	Temp	°C	49	41	55.54	112	46	58.65	921	1902	2008	3033890
Pincher Creek	Precip	mm	49	31	27.25	113	58	38.52	1190	1915	2007	3035206
	Temp	°C	49	31	27.25	113	58	38.52	1190	1895	2008	3035206
Vauxhall	Precip	mm	50	2	52.66	112	8	34.18	779	1914	2007	3036682
	Temp	°C	50	4	0	112	6	0	778.8	1913	1957	3036680
	Temp	°C	50	3	0	112	8	0	778.8	1957	1991	3036681

Table 2.1. (continued)

Station	Data	Unit	Northing			Westing			Elevation	Start	End	ID
Vauxhall	Temp	°C	50	10	57.08	112	7	19.04	760	1991	2008	3036690
Drumheller	Precip	mm	51	26	58.22	112	53	24.85	719	1954	2007	3022136
	Temp	°C	51	28	0	112	43	0	687.3	1956	1968	3022120
	Temp	°C	51	28	0	112	52	0	719.3	1968	2008	3022136
Jenner	Precip	mm	50	42	20.41	111	10	54.06	755	1961	2007	3023560
	Temp	°C	50	43	20.02	111	11	47.07	755	1915	2008	3023560
Olds	Precip	mm	51	46	46.19	114	6	6.26	1040	1914	2007	3024920
	Temp	°C	51	47	0	114	6	0	1040.3	1914	2008	3024920
Vulcan	Precip	mm	50	32	0	113	4	0	990.6	1954	1968	3036880
	Precip	mm	50	24	0	113	5	0	1048.8	1974	2000	3036881
	Temp	°C	50	32	0	113	4	0	990.6	1954	1968	3036880
	Temp	°C	50	24	0	113	5	0	1048.8	1974	2000	3036881
Red Deer	Precip	mm	52	17	0	113	49	0	859	1904	1974	3025440
	Temp	°C	52	17	0	113	49	0	859	1904	1974	3025440
	Precip	mm	52	18	39	113	47	32	904	1975	2007	3025480
	Temp	°C	52	18	39	113	47	32	904	1975	2007	3025480

Prior to modelling flow, all data from the mountain blocks were pooled and averaged, as was the data from the plains blocks. This reflects the two regions present in the blocked design (Neter, Wasserman, and Kutner 1996). Then the two regions were also compared against each other, using Variance Inflation Factor (VIF) to determine if the two separate regions were necessary (Myers 1990; Mansfield and Helms 1982). VIF is a statistic that tests for multicollinearity between the covariates. VIF reports how much of a covariates variability can be explained by another covariate in the model as a result of multicollinearity, based on the equation $VIF_i=1/(1-r_i^2)$ where r_i^2 is the co-efficient of determination (Craney and Surles 2002). Cut-off values for VIF vary greatly throughout the literature, as there is no formal method to determine what value of a VIF is too large. The most common cut-off values range from 5 to 10, but it is proposed that cut-off values as low as 1 or 2 are also possible (Belsey, Kuh, and Welsch 1980; C. Robinson and Schumacker 2009; Craney and Surles 2002; Menard 1995). For this project, a conservative VIF value of 4 was chosen.

Using this cut-off value, it was determined that the amount of precipitation that fell in the two regions was found to be significantly different, but the three temperature variables (minimum, maximum, and mean) were not significantly different between the two regions (Table 2.2). Therefore analysis proceeded with precipitation having two regions (mountains and plains), and temperature having one (basin).

This results in a total of 60 variables (12 precipitation variables for 2 regions and 36 temperature variables for 1 region) that were carried forward into predictive flow model development. Multiple linear regression and AIC were used to develop the minimally adequate predictive flow models (Whittingham et al. 2006).

Table 2.2. VIF values comparing the precipitation, minimum temperatures, mean temperatures, and maximum temperatures of the mountain region with the plains region. This table shows high multicollinearity between the two regions for all three temperature variables, but not for the precipitation variable.

VIF	Precipitation	Maximum temperature	Mean temperature	Minimum temperature
Jan	1.6520	5.8653	6.6855	6.8923
Feb	1.5394	5.8159	8.4566	9.5026
Mar	1.3775	5.3155	7.2197	6.4316
Apr	1.3187	7.1502	9.8987	7.7915
May	1.6662	7.0698	9.8940	4.7189
June	2.5258	6.0786	7.0434	4.3893
July	2.0091	5.9909	5.8709	3.0358
Aug	2.9557	8.0193	9.7202	3.4729
Sept	2.8378	13.5110	17.0398	6.3037
Oct	1.9436	5.8782	9.6457	6.1156
Nov	1.8992	6.9959	7.4584	7.2319
Dec	1.5968	6.5043	7.6228	7.7546
Winter	1.9934	5.2154	6.6328	7.3174
Spring	1.3623	4.3826	5.2613	4.5282
Summer	1.5497	5.5345	4.5868	5.8709
Autumn	2.4181	5.7295	5.2160	7.1897

2.2 *Data Collection and Exploration*

2.21 *Climate*

Climate data was collected from existing Environment Canada databases for various points along the Bow, Oldman, Red Deer and South Saskatchewan Rivers (Table 2.1). Temperature data was available on the Environment Canada Website (Government of Canada 2010a). This included daily maximums, means and minimums. The temperature data available at this site was already homogenized, correcting for changes in site location, instrumentation, and observer differences. This was accomplished by using regression models (Vincent and Gullett 1999). Sites were also tested for homogeneity with neighbouring stations using a regression technique based on models outlined in Vincent (1998).

Data exploration started after the collection of the survey data. Raw data from the 15 climate stations were examined. Due to the nature of the dataset (long term survey data), it was of particular interest to find and remove any potential outliers. This was done by constructing boxplots for each station on a monthly basis and inspecting the data visually. Extreme climate events were separated from outliers by corroborating any potential extreme climate event with neighboring stations. Using this system, potential outliers were identified, but none were removed.

Normality of the data was also tested. Daily temperature values were used to test this assumption by producing multiple histograms. A histogram was produced for each variable on a monthly basis. The histograms and QQ plots showed that temperature data was normally distributed. (Michael 1983). As such, analysis proceeded without transforming the temperature data.

Precipitation data was also available from the same Environment Canada Website (Government of Canada 2010b). Precipitation data was available as daily totals for snow, rain, and total precipitation, although only total precipitation was used in building the flow models due to GCM/RCM restrictions. The data had already been corrected for historical inaccuracies (Mekis and Hogg 1999). Snow and rain were corrected separately of each other. Rain data was corrected for differences in gauges (Devine and Mekis 2008). Adjustments were also made to snowfall data to account for different density measurements (Mekis and Hopkinson 2004).

Data collection and exploration proceeded in the same fashion for precipitation variables as it did for temperature. The two precipitation regions were checked for outliers, and tested for normality. Within the precipitation dataset, no outliers were observed, and no transformations were performed.

2.22 *Flow*

2.221 *Historic Flow*

Historic flow data was collected from a pre-existing database that was available online at the Environment Canada Water Office website (Government of Canada 2009a). This site contained data collected by the National Hydrometric Program from existing and discontinued hydrometric monitoring stations. Data was available as daily and monthly mean flows, and was collected for sites closest to Leader SK. These sites were near Lemsford (station 05HB001) and Highway 41 (station 05AK001).

2.222 *Naturalized Flow*

Historic flows were not used in model development, as changes in these flows are affected by anthropogenic activities, and not necessarily indicative of a climate conditions. For this reason flow was naturalised and used in model development.

Naturalized flow data is available for the Alberta portion of the watershed, as well as for one location in Saskatchewan. Naturalized flows were developed from historic flow data, but had removed the effects of anthropogenic impacts on flow. This was done in a multi-step process that started with daily-recorded flows, and sequentially projected adjustments were added. Adjustments that were considered included the effect of evaporation from lakes and reservoirs, evapotranspiration, irrigation use, hydroelectric power use, and municipal water use. Methods chosen for estimating the evaporation and evapotranspiration were those developed by Morton (F. I. Morton 1971; F. I. Morton 1975; F. I. Morton 1976). Diversions that were considered when developing the naturalized flows are presented in Appendix A. Irrigation use data was supplied by the thirteen various irrigation districts in the SSRB in the form of gross diversions. Return flow back to the river from irrigation were calculated by using climatological data to construct an index of aridity. Industrial and municipal diversions only accounted for under 3% of use, hence only the withdrawals from the major cities of Calgary, Lethbridge, Medicine Hat, Red Deer and Drumheller were used (Alberta Environmental Protection Natural Resources Services 1998).

Some of the flow data used to develop the naturalized flow were not complete for the entire period that was studied (1913-1995). These sets were completed by using the U.S. Army Corps of Engineers Stream flow Synthesis and Reservoir Regulation routing model (Rockwood 1968; Schermerhorn et al. 1968). This was done by the Water Sciences Branch of the Alberta Environmental Protection, Hydrology Section. They also developed the routing configurations for the application of this model to the SSRB.

Naturalized flow data was presented as weekly-naturalized flows, which were then combined to develop monthly mean naturalised flow (Table 2.3). Naturalized flows are the flows that were brought forward into the development of the predictive flow models. The naturalised flow data that was used for model development was worked up for a location just downstream of the SSR and Red Deer River confluence, not far from Leader SK (see Fig. 2.1).

Table 2.3. The calendar weeks that were combined when developing monthly naturalized flows.

	Calendar Days	Weeks Included	Number Of Days
January	1-31	1-4	28
February	32-60	5-8	28
March	60-90	9-13	35
April	91-120	14-17	28
May	121-151	18-21	28
June	152-181	22-26	35
July	182-212	27-30	28
August	213-243	31-34	28
September	244-273	35-39	35
October	274-304	40-43	28
November	305-334	44-47	28
December	335-354	48-51	35

2.3 *Model Development*

Predictive flow models for this project were developed using multiple linear regression, and AIC (Whittingham et al. 2006; Zhang et al. 2010). The explanatory variables in this study are: minimum, maximum, and mean temperatures for the basin, as well as total precipitation for both mountain and plains regions. These variables were collected as daily values, but were then averaged into monthly mean variables at each station. These variables were then combined and averaged within each region. To capture potential lags in time between flow and climate, the monthly climate variables were also all lagged by one year. This allowed data from the preceding 12 months to be used when modeling flows.

2.31 *Correlation of Temperature Variables*

Due to the high multicollinearity between the three temperature variables: mean, maximum and minimum (Fig. 2.2), a correlation study was first carried out (Zhang et al. 2010). The temperature variable that had the greatest correlation with flow was carried forward into the MLR and AIC analysis, with the other two temperature variables being discarded (Table 2.4). This reduced the number of variables being carried into the maximal model for each month from 60 to 36 (12 mountain, 12 plains precipitation variables, and 12 temperature variables). The variables entered into each month's maximal flow models are presented in Table 2.5. Maximal models are the models that include all of the covariates in the study, and are the starting point when developing minimally adequate models.

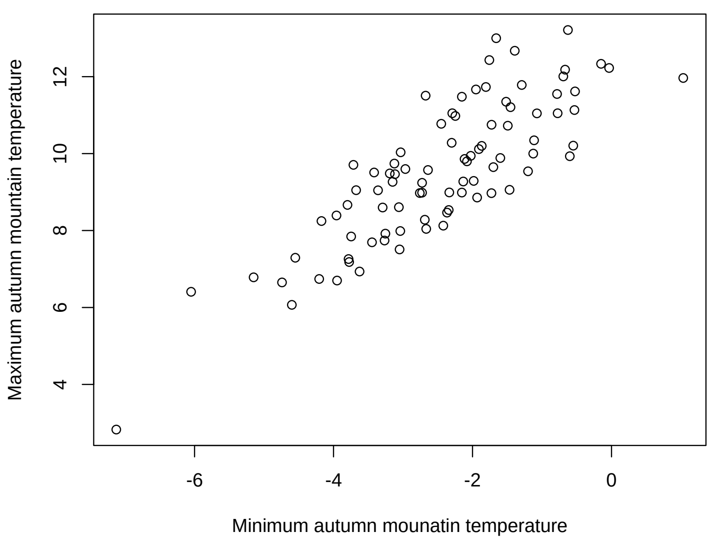

Figure 2.2. Mountain autumn minimum temperature versus mountain autumn maximum temperature showing the high degree of multicollinerity present between these temperature covariates

2.32 *Multiple Linear Regression*

As previously mentioned, predictive flow models were developed using multiple linear regression and AIC (Whittingham et al. 2006; Zhang et al. 2010). All statistics were worked up in the R statistical environment (R Core Team 2012). Multiple linear regression was employed due to the multiple continuous covariates (Bolker 2008). All potential covariates were entered into a maximal model, and backwards regression was employed to reach minimally adequate models for each predictive flow model developed (Whittingham et al. 2006). Covariates were sequentially dropped based on their significance with the least significant covariate being dropped. The model was then re-tested until there was a rise in AIC (> 2 points) (Burnham and Anderson 2002).

There has been some uncertainty about the validity of using MLR, because of some limitations and assumptions of this approach (Derksen and Keselman 1992; Burnham and Anderson 2002). One potential problem with using a stepwise multiple linear regression technique is the potential for bias in parameter estimation. Bias can arise in this procedure, as the minimally adequate model is developed through parameter inference, or testing to see if a parameter is significantly different from zero (Chatfield 1995). This issue is also referred to as model selection bias, and can occur when model selection proceeds without reference to other possible models. For this project, AIC was used in model selection in order to account for other models.

Table 2.5. Temperature variables that were included in each monthly maximal model. Each maximal model also included twelve mountain precipitation, and twelve plains precipitation variables.

		Monthly predictive flow model											
		Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Temperature variables with the highest correlation to flow	Jan	min	min	max	max	max	max	max	min	mean	min	max	mean
	Feb	mean	min	min	max	max	max	mean	min	min	min	max	max
	March	min	max	max	mean	mean	min	min	min	min	max	max	max
	April	min	min	min	max	max	mean	max	min	min	min	min	max
	May	mean	max	min	mean	max	max	max	max	max	max	max	mean
	June	min	max	mean	mean	min	max	max	max	mean	max	max	mean
	July	min	max	max	mean	min	min	mean	max	max	max	max	max
	Aug	mean	min	mean	mean	min	max	min	min	max	max	max	max
	Sept	mean	min	max	max	max	min	max	min	max	max	max	max
	Oct	max	max	max	max	max	min	min	min	min	max	max	max
	Nov	max	max	max	max	min	min	max	min	min	max	min	max
	Dec	mean	min	max	max	max	mean	max	min	max	min	min	min

There is also a second issue that needs to be dealt with when using this method for model development. This problem is based on the algorithm that is used in backwards elimination, and how it can impact or affect the selected model (Derksen and Keselman 1992). When using this technique, both the number of covariates and their order have been found to influence model selection (Grafen et al. 2002).

As previously stated, there were 36 covariates used in each maximal model, which were then worked into minimally adequate models containing between 6-13 covariates each. When entering the covariates into the maximal model, the following formula was used: flow ~ mountain precipitation + plains precipitation + basin temperature. This order was decided upon, as precipitation (particularly mountain precipitation) is believed to have the greatest influence on flows of the SSR (Halliday 2009; Comeau, Pietroniro, and Demuth 2009). As the covariates entered first are more likely to be found significant, the variables that were believed to be the most influential in determining flow were entered first in order to help account for this (Derksen and Keselman 1992). Although this issue cannot be fully overcome, it is acknowledged as a limitation of this type of approach.

There is one final issue with using multiple linear regression to arrive at a minimally adequate model. This issue arises because the goal of MLR is to arrive at a single, best model (Whittingham et al. 2006). This is not a computational issue, but rather a caution on how to interpret models produced by this procedure. This procedure moves forward, sequentially dropping covariates until a minimally adequate model, or the most parsimonious model is achieved. This model may or may not fit the data equally as well as another model that is not stated or presented. Not acknowledging this may lead to false, or misleading conclusions when interpreting the minimally adequate model. As a result of this, it is recognised that the models presented as a result of this project may have counterparts that contain different covariates that are equally as capable of fitting the data.

2.33 *Akaike's Information Criterion*

Using AIC has gained popularity over the years, and is becoming widely used in many different fields such as ecology, medicine, sociology and astrophysics (Biesiada 2007; Anderson, Burnham, and White 1994; Hsu et al. 2010; Wang et al. 2003).

Acknowledging the issues inherent to a statistical procedure is important, as is trying to account for any problems that may arise because of them. Literature has pointed out the issues that arise using techniques like multiple linear regression (Burnham and Anderson 2002; Anderson, Burnham, and Thompson 2000). This has led to alternative model selection procedures, one of which is Akaike's Information Criterion (AIC).

AIC was proposed by Hirotsugu Akaike in 1974 as a measure of the goodness of fit of a statistical model. It is based on the concept of entropy, trying to quantify the trade-off between the precision and the complexity of the model (Bozdogan 1987). AIC is a tool that can be used for model selection. It is based on the general equation $AIC=2k-2\ln(L)$, where k is the number of parameters in the model, and L is the maximized value of the likelihood function for the model being tested. This set up rewards goodness of fit while penalizing the inclusion of extra parameters. This helps to discourage over-fitting, and aims to find the model that can best describe the data with the fewest parameters.

2.34 *Time Steps*

Three different time steps were initially considered for the covariates used in the development of the predictive flow models. These were annual, seasonal, and monthly. These time steps mimic the output of various global and regional climate models. The use of an annual time step was discarded based on the inability to infer useful information from annual covariates into their desired ecological context. This is because too much of the variability present in the system is lost when the covariates cover such a large amount of time. Consequently, only seasonal and monthly covariates were used in the development of predictive flow models.

Predictive flows models were initially developed using seasonal time steps for the covariates. Seasons were defined as winter (December - February), spring (March - May), summer (June - August), and autumn (September - November) as per Environment Canada's Canadian Climate Change Scenarios Network (Government of Canada 2013). This approach was taken in an effort to reduce the number of variables being entered into the maximal models. This approach was later abandoned as using seasonal time steps was found to be too coarse of a variable, and the models developed were not able to predict flows accurately.

Covariates were subsequently changed from a seasonal scale to a monthly scale. This was done as a compromise between the coarseness of the covariate, and the number of covariates. Models that were developed using the monthly time steps were the models that were carried forward.

2.35 *Model Validation*

Model validation is the process of deciding whether or not a model is able to accurately describe or represent the data. In this case the models are describing flow. The use of various model validation techniques has been well documented (Gentil and Blake 1981; Reynolds, Burkhart, and Daniels 1981; Mayer and Butler 1993; Oreskes, Shrader-Frechette, and Belitz 1994; Robinson and Froese 2004). Debate surrounding the necessity of validating models persists as well (Stone 1977; Rykiel Jr 1996). For example, Stone (1977) and Rykiel (1996) suggest that model validation does not necessarily prove legitimacy, but instead only helps to enhance the model's credibility for the user.

Procedures for validating models have been discussed considerably in the literature. As there are many different types of models, there are also a large number of approaches to model validation. These include an accuracy test based on X^2 (Freese 1960), a lack of fit F-based statistic (Jans-Hammermeister and McGill 1997), as well as various cross validation techniques (Kohavi 1995; Shao 1993; Boyce et al. 2002). Each approach has different strengths, and weaknesses, with the best approach needing to being chosen on a case-by-case basis.

Using the idea presented in Rykiel (Rykiel 1996), that model validation should be used as a tool to enhance credibility, and not necessarily prove legitimacy, the statistical monthly flow models were validated using k-fold cross validation (Kohavi 1995). Cross validation is a way of measuring the predictive performance of a statistical model, although it has also been used as a method for model selection (Kohavi 1995). Cross validation is a useful technique to address the over-fitting of the models (Harrell, Lee, and Mark 1996). Over-fitting refers to a situation when a model needs more information than the data can provide and usually results in biased error estimates. Over-fitting can be caused by using the same data to validate the model that was used to initially develop the model. K-fold cross validation is one way to overcome the over-fitting bias.

K-fold cross validation is also a technique that can be used to determine how well a statistical model fits the data while addressing issues of over-fitting. It does this by holding back a portion of data when training the models, and then uses this withheld data to test the models fit. K-fold cross validation involves splitting the data into k sets (or folds), with k-1 folds being used as training sets and the remaining fold being used as the testing set. The training sets are the portion of data that the model is fit with, and the testing set is used to test the fit of the model. With k-fold cross validation, this validation procedure is carried out k times, with each fold only being used once in the testing procedure. For this study, k=10. K does not have to equal ten, but this is the most commonly used value when using this technique. Mean square error (totalled across all k folds) will be the measure of how well the model fits the data (Table 2.6).

An equivalence approach to model validation was also undertaken (Wellek 2010; Robinson, Duursma, and Marshall 2005). This approach still agrees with the idea that model validation should help improve model credibility, and not necessarily legitimize the model (Rykiel 1996). The equivalence approach tests the null hypothesis, in this case stating that the populations (historical and naturalized flows) are different. Data are used to prove that the there are no difference between populations. Using this concept, model outputs were tested against the historical data to see how similar the two groups of data were. This step in model validation did not follow the entire procedure outlined in Robinson and Froese (2004), instead it was decided to take a more streamlined approach. The data was looked at from the perspective of a paired t-test to determine how similar the real data were from the model outputs when the models were used to hind-cast. The results of this test are presented in Table 2.7.

Table 2.6. MSE totalled across all ten folds for the k-fold cross validation of the predictive flow models. Greatest error associated with the models that predict summer flows, and the least error in the models that predict the winter flows.

Month	Mean Square Error
January	458
February	314
March	1553
April	2754
May	5941
June	4410
July	2590
August	1739
September	1719
October	1443
November	851
December	298

Table 2.7. Mean and standard deviations for the modeled flows and the naturalised flows, as well as the paired t -test values and their significance. For all months, modeled flows are not significantly different from the naturalised flow except for the month of December where the two flows are significantly different. This demonstrates that 11 of the 12 predictive monthly flow models predict flows that are not significantly different than the historic naturalized flows . The December model predicts flows that are significantly different than historic naturalized flows.

Variable	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
mean (models)	55.4	63.9	122	262	434	883	563	333	226	180	122	65.9
mean (naturalized flows)	52.7	59.8	119	268	430	871	587	339	224	178	120	60.8
Standard deviation (models)	14	17	52.7	118	117	248	184	74.5	63.3	64.7	28.8	20.8
Standard deviation (naturalized flows)	21.5	22.8	52.9	137	148	297	226	99.4	55.5	62.2	32.7	21.4
t-value	0.606	0.865	0.297	-0.29	0.133	0.352	-0.92	-0.40	0.274	0.252	0.584	2.7
degrees freedom	86	86	86	86	86	86	86	86	86	86	86	86
p-value	0.55	0.39	0.77	0.77	0.89	0.73	0.36	0.69	0.78	0.80	0.56	0.01

3.0 Applying Flow Models

3.1 *Global Climate Models Selection*

Future flow scenarios were developed using the models discussed in Chapter 2 with output from five different global climate models. For this project, the five global climate models (GCM) that were selected for use in development of the future flow scenarios each represented five different future climates. The future climates were a hot future, a cold future, a wet future, a dry future, and an average future. Each potential future is represented by a single scenario that came from a different GCM. The five GCM's selected for use in this project are listed in Table 3.1. The predictive flow models were ran separately with each of the five different future climate predictions and then averaged together to prepare the future flow scenarios (Appendix C).

Table 3.1 The global climate models (GCMs) and the specific special report on emission scenarios (SRES) selected for use in the development of future flow scenarios. For further information regarding the GCM's, refer to Appendix D.

Future Climate	GCM	SRES Scenario
Hot	Miroc3.2medres(mean)	SR-A2
Cold	GISS-AOM(mean)	SR-B1
Wet	BCM2.0(run 1)	SR-A1B
Dry	CSIROMk3.0(run 1)	SR-B1
Average	ECHO-G(mean)	SR-A2

3.11 *Validation of GCM's Selected*

The selection of GCMs followed the guidelines outlined by IPCC and the United Nations Institute for Environmental Studies (Smith et al. 1998; Carter, Hulme, and Lal 2007). These guidelines consider the importance of model vintage, model resolution and validity, as well as, representativeness of results when choosing GCM's to be used in impact studies. All four guidelines were considered when selecting which GCM's to employ in this study.

3.111 *Vintage*

Model vintage is important when selecting models for climate impact studies (IPCC 2007). The IPCC (2007) recommends that the newest versions of models be employed. This is based on the assumption that the newest versions will have incorporated more recent knowledge, more feedbacks processes, and may be of a finer spatial resolution (IPCC 2007). To date, five different assessment reports have been released by the IPCC, the first in 1990, the second in 1995, third in 2001, and fourth report in 2007. A fifth report was recently released near the end of 2014. All GCM's used in this project came from Assessment Report 4 (AR4) that was released in 2007. These are some of the most recent models, but have had time to be reviewed and used in many publications.

3.112 *Resolution*

The second important guideline for model selection is model resolution (Smith et al. 1998). Larger resolution models (GCM's) are typically able to incorporate more atmospheric and oceanic processes than the finer resolution models (RCM's). Finer resolution models are able to provide output at a smaller geographic scale, however, there are some disadvantages with finer resolution models associated with edge effects and downscaling. For further differences between RCMs and GCM's, refer to Table 3.2.

Table 3.2. Comparison between GCM and RCM.

Global Climate Models	Regional Climate models
-information physically consistent	-highly resolved information
-long simulations, different special report emission scenarios (SRES) available	-physically based
-many variables	-better representation of mesoscale phenomena and some weather extremes
-data readily available	-lack 2-way nesting
-coarse scale information	-dependant on usually biased inputs from the forcing of GCMs
-daily characteristics may be unrealistic except for large regions	-fewer scenarios available

Initially, regional climate models were considered for this project. However RCMs were not used in the final development of future flow scenarios because only one RCM (CRCM4.2.3 [SR-A2]) had the appropriate variables as dictated by the predictive flow models. The five climate models that were selected for developing the final future flow scenarios were all GCM's. The resolution, as well as the different layers and biases included in the five different GCM's are listed in Appendix D.

3.113 *Validity*

Validity refers to the ability of a model to predict a future climate that is physically plausible in the system it is designed to represent (Smith et al. 1998). This is an important criterion for selecting a potential model for use in impact studies (Smith et al. 1998). In order to determine if a model was physically plausible for use in this study, a multi-step process was initiated. This process started by investigating historic climate. This is important, as past climate is key in predicting future climate. The historic information indicates that the prairie climate has been changing. The SSRB has seen an increase in average temperatures between 1-4 in the last 80-118 years, and a decrease in the total annual precipitation (Schindler and Donahue 2006; Gan 1998). While the decrease in precipitation is a significant trend, it is scattered and has a high amount of spatial variability (Gan 1998). Looking even further back by using paleolimnology and tree-ring studies, we can see that the last century was less stable, and warmer than the past (Sauchyn et al. 2002; Sauchyn and Skinner 2001; Laird et al. 2003).

This trend of a changing climate is expected to continue well into the future. According to ensemble scenarios constructed by the Canadian Climate Change Scenarios Network (hosted by Environment Canada), this region is predicted to see a temperature increase between 3-4°C increase by the 2080's (Government of Canada 2013). These same ensemble scenarios are predicting an increase in precipitation of 6-8.5% by the 2080's. While historic studies have seen a decrease in precipitation (Gan 1998; Ripley 1986), future predictions are showing a slight increase. However, it is acknowledged that there is much uncertainty surrounding the predictability of precipitation (Murphy et al. 2004; Loarie et al. 2009).

Acknowledging that GCM's are not as accurate at predicting precipitation as they are at predicting temperature (Smith et al. 1998; IPCC 2007). Dealing with the uncertainty can be challenging. One way used to deal with this uncertainty is to use large ensemble scenarios to gauge what future climates may be valid for a region. An ensemble scenario is what results when the outputs from many GCM's are averaged together. Using an ensemble reduces the uncertainty introduced by any individual model. Following this idea, conservative estimates on temperature and precipitation changes provided by the ensemble scenarios supplied by Environment Canada were used to help judge the validity of the selected GCM's (Table 3.3).

Table 3.3. Ensemble scenario predictions for changes in temperature and precipitation in the SSRB when compared to a baseline of 1961-1990. These were used to judge the validity of GCM climate predictions.

Future Time Period	Temperature Change	Precipitation Change
2020's	1-2°C	2-3.5%
2050's	2-3°C	4-6%
2080's	3-4°C	6-8.5%

3.114 *Representativeness of Results*

Smith et al. (1998) strongly recommended that more than one GCM be applied in impact studies, and that the GCM's used also represent a variety of different futures. As there is uncertainty surrounding the projections of GCM's, a variety of future scenarios is advised to account for this uncertainty. A minimum of two different futures is recommended, but it is best practice to include as many as possible. This study attempts to incorporate five different future scenarios. Each scenario represents one of either a hot, cold, wet, dry or average future. Important to note that the average scenario does incorporate anticipated climate changes, it is just representative of a median change.

3.2 *Extraction of Data from GCM Database*

All GCM data were available online from Environment Canada. Compiling the data from this site was a multi-step process. This process involved using the coordinates of the region to guide the extraction of the data. The coordinates used were for the entire region (mountain, plains or basin), and not just one point. This ensured that the data taken from the GCMs was representative of the entire region, and not just a select portion of it. The coordinates used for collection of the mountain region was 51°15.6′ N to 49°0′ N and 116°7.8′ W to 114°13.2′ W. For the plains region, the coordinates were 51°15.6′ N to 49°0′ N and 114°13.2′ W to 110°24′ W. When collecting data for the basin, both the mountains and plains region were combined (51°15.6′ N to 49°0′ N and 116°7.8′ W to 110°24′ W). The data collected in this fashion reflect the average for all GCM gridboxes that are lying within these coordinates boundaries. GCM gridboxes are predetermined geographical units that reflect the resolution of the various climate models (higher resolution = smaller gridbox). This is one drawback of using the GCMs versus the RCMs as the spatial resolutions are not as fine.

After entering the appropriate coordinates, the time scale for the output was selected. There were three options for the time scale: annual, seasonal and monthly. Only monthly and seasonal outputs were collected because annual outputs have limited ecological significance when used in the context of this project. Reasoning for this is that data averaged over the entire year reduces much of the climate variation that the models are trying to capture, and subsequently model. As the monthly and seasonal data were collected, it was assembled for all future time periods: 2020's, 2050's, and 2080's.

A baseline period of 1961-1990 was used for all data collected from the GCM's. A baseline is a reference period that future predictions are compared to in order to evaluate changes. The other option for a climate baseline was the 1971-2000 period. However, the 1961-1990 baseline was selected because later reference periods may already be under the influence of anthropogenic impacts (IPCC 1992), for example the influence of sulphate aerosols (Karl and Trenberth 2003).

3.3 *Development of Future Flow Scenarios*

Future flow scenarios were developed once the necessary variables were extracted from the GCM's. The extracted data was fed into the predictive flow models, resulting in each future time period having a discreet future flow scenario. Approaching the development of future flow scenarios in this manner kept any biases of any particular GCM to a minimum as all five GCM's were used with equal weighting. Adopting this procedure also follows the IPCC's (2007) recommendations for use of scenario data in adaptation strategies.

3.31 *Study Site*

Future flow scenarios were applied to habitat data from the secondary study site at Clarkboro Ferry (Fig 2.1). This secondary site is located downstream from Saskatoon SK, between Warman and Aberdeen on grid #784. The substrate at this site varies from sand, to gravel, with some pockets of mud and cobble. The bathymetry of this part of the river shows that the depth varies from 43 cm to 269 cm (Fig. 3.1). This area was selected for this intensive habitat study, along with other sites on the North Saskatchewan River, and the main stem of the Saskatchewan River by the WSA. Site selection was based on risk assessments previously carried out on the Saskatchewan River System. Parameters that were evaluated in these risk assessments include the quality foraging habitat for lake sturgeon available, impact of flow, and the abundance of food items (Pollock et al. 2009).

3.4 *Habitat Models*

Lake sturgeon habitat models used in this project were developed and provided by the Saskatchewan Water Security Agency (WSA).

3.41 *River 2D*

River 2D is a computer based program customised to evaluate fish habitat. WSA used this software to develop the lake sturgeon habitat models that were used in this study.

Different types of data were required to develop these habitat models. Data were collected between May and September of 2011 for the Clarkboro site. Bathymetry, water elevation, substrate type, and flows were recorded (Pollock et al. 2012). Depth, substrate, and UTM data were collected using a Biosonics bathymetric unit, which was mounted on a boat. A Real Time Kinematic (RTK) unit was used simultaneously to develop the surface water elevation data.

The collection of this data happened in three separate steps. It started initially by passing survey transects as close to the shoreline of the study site as possible, as well as at the top and the bottom of the reach, creating a closed rectangle. The second step involved collecting data along 5-6 more transects, running parallel to the shoreline. Finally, transects were run perpendicular to the shoreline, approximately every 300 meters to create a grid pattern from the intersecting transects. An example of how this data was collected in the river is presented in Figure 3.4.

Flow data were collected using a SonTech River Surveyor. The surveyor was mounted to the boat, and data were collected by running transects perpendicular to the shoreline, every 500-600 meters, but not parallel as was done when collecting the data for the bathymetry (Fig. 3.2) (Pollock et al. 2012).

3.411 *Habitat Model Development*

Model development with this program involved four steps (Pollock et al. 2009). The first three steps involved the use of the data collected in the field to construct a bed file, a mesh file, and a River2D model. The final step involved pairing field data with habitat preference information specific to lake sturgeon in this area. Department of Fisheries and Oceans provided this specific lake sturgeon habitat information to the WSA for use in their project.

The lake sturgeon habitat preferences that were developed by the DFO were created for five different life stages: spawning, fry, juvenile, sub-adult and adult. The habitat suitability indices for the five life stages are based on flow, depth and substrate preferences. The habitat preferences for each life stage were incorporated into River2D models in the fourth step of the habitat model development (described previously). This was accomplished by using habitat suitability indices based on flow, depth, and substrate preferences of each age class (Tables 3.4-3.6) and applying them to conditions that are present in the river (e.g., flow and depth). The completed models are presented in Table 3.7.

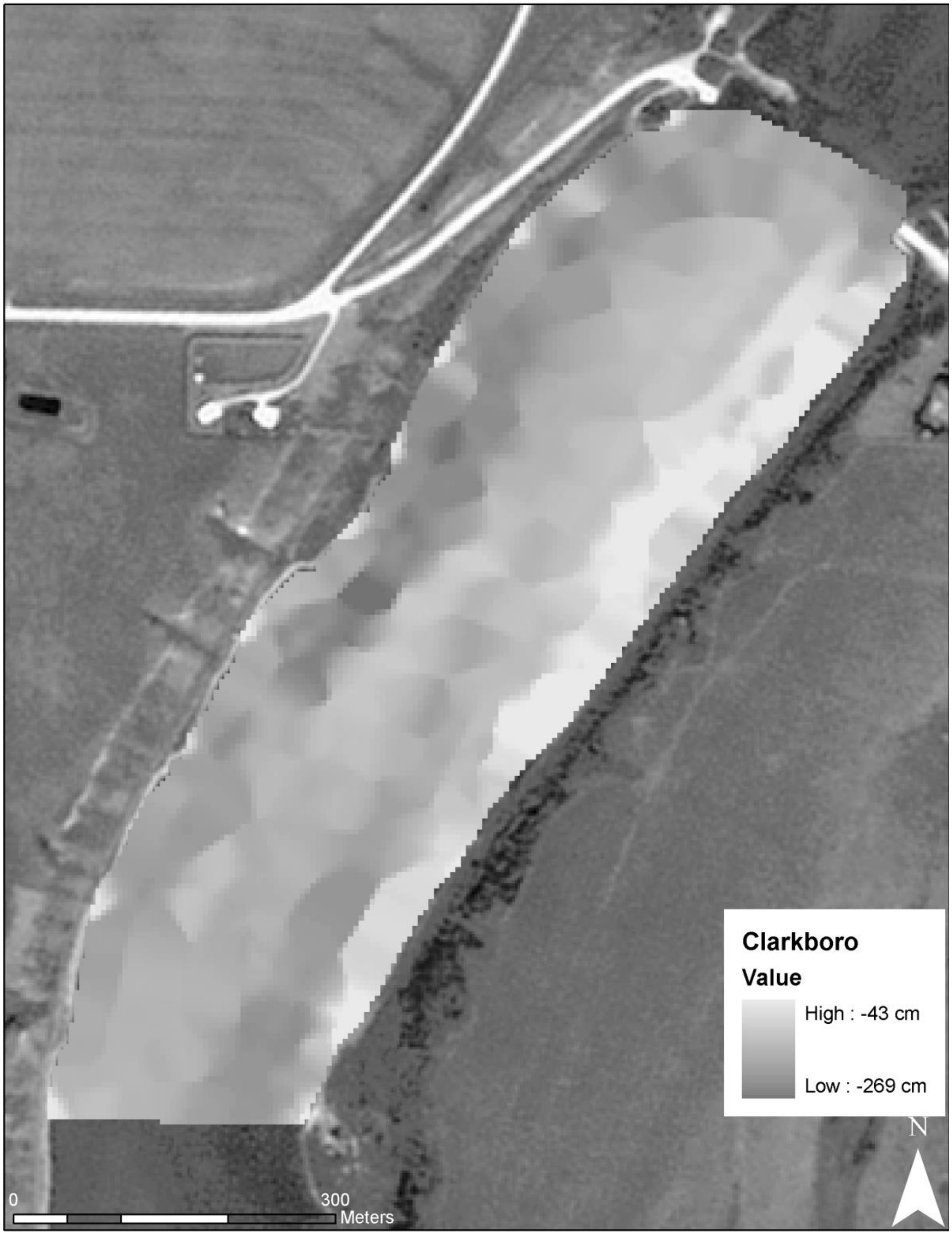

Figure 3.1. Bathymetry of the secondary study site at Clarkboro Ferry in 2008 which depicts the range in depth. The darker shades are deeper. The study site has a max depth of 2.23m, with the elevation of the site ranging from 0.43m to 2.69m below sea level. The negative values are present in the key as the elevation of the river is below, not above, sea level. (Image provided by WSA).

Figure 3.2. Example of how flow was measured in transects (in white) at Clarksboro site for the development of a lake sturgeon habitat model (image provided by WSA).

3.5 *Application of Future Flow Scenarios*

The habitat models that were developed with River2D were combined with the future flow scenarios. The habitat models are linear equations that when flow is entered (in cms), it is possible to solve for effective habitat area (in hectares). These models are presented in Table 3.7. The future flows scenarios (Appendix C) were fed into the habitat models and effective habitat area was solved for each of the different life stages.

3.6 *Baseline Habitat*

In order to make a comparison in the availability of habitat for lake sturgeon, an understanding of the amount of habitat that was present, previous to the future time steps is necessary. As this data is not available, an approximation was made. A baseline time period (1961-1990) was chosen. This baseline period is the same baseline that was used in the development of the flow models, and was chosen for the same reasons. Flows from this baseline period were used with the habitat models developed by WSA. This provided an approximation of the available habitat for lake sturgeon during the baseline period, and allowed for comparisons to be made. Baseline habitat was calculated for each of the five life stages.

3.7 *Future Habitat*

Future habitat was compared to the baseline habitat. All five life stages were compared to their respective baseline habitats, and the difference between the baseline and future habitat was calculated. The comparison is reported as percentage change in habitat.

Table 3.4. Velocity information used in the River2D model. This information, along with depth and substrate type was used to help dictate habitat suitability for lake sturgeon in the Saskatchewan River System. This data was based on expert opinion, and adapted from Fisheries and Oceans (2009).

Spawning		Fry		Juvenile		Sub-Adult		Adult	
Velocity (m/s)	suitability (_/1)	Velocity (m/s)	suitability (_/1)	Velocity (m/s)	suitability (_/1)	Velocity (m/s)	suitability (_/1)	Velocity (m/s)	suitability (_/1)
0	0	0	0	0	1	0	1	0	1
0.05	0	0.05	0	0.05	1	0.05	1	0.05	1
0.1	0	0.1	1	0.1	1	0.1	1	0.1	1
0.25	0	0.25	1	0.25	1	0.25	1	0.25	1
0.3	0.25	0.3	1	0.3	1	0.3	1	0.3	1
0.4	0.5	0.4	0.5	0.4	1	0.4	1	0.4	1
0.5	1	0.5	0	0.5	0.5	0.5	1	0.5	1
0.8	1	0.8	0	0.8	0.25	0.8	1	0.8	1
1	1	1	0	1	0	1	0.5	1	1
2	0	2	0	2	0	2	0	2	0

Table 3.5. Depth information used in the River2D model. This was the information used along with velocityand substrate type to help dictate habitat suitability for lake sturgeon in the Saskatchewan River System. This data was adapted from Fisheries and Oceans (2009).

Spawning		**Fry**		**Juvenile**		**Sub-Adult**		**Adult**	
Depth (m)	suitability (_/1)	Depth (m)	suitability (_/1)	Depth (m)	suitability (_/1)	Depth (m)	suitability (_/1)	Depth (m)	suitability (_/1)
0	0	0	0	0	0	0	0	0	0
0.05	0	0.05	0	0.05	0	0.05	0	0.05	0
0.3	0	0.3	0.25	0.3	0	0.3	0	0.3	0
0.5	0	0.5	0.5	0.5	0	0.5	0	0.5	0
1	0	1	1	1	0.25	1	0.25	1	0.25
3	0.5	3	1	3	0.5	3	0.5	3	0.5
4	0.5	4	1	4	1	4	1	4	1
7.5	0.25	7.5	1	7.5	1	7.5	1	7.5	1
8	0	8	1	8	1	8	1	8	1
10	0	10	1	10	1	10	1	10	1

Table 3.6. Substrate information used in the River2D model. This was the information used along with depth and velocity to help dictate habitat suitability for lake sturgeon in the Saskatchewan River System. This data was adapted from Fisheries and Oceans (2009).

Spawning		Fry		Juvenile		Sub-Adult		Adult	
Substrate type	Suitability (_/1)	Substrate type	suitability (_/1)	Substrate type	suitability (_/1)	Substrate type	suitability (_/1)	Substrate type	suitability (_/1)
Sand/silt	0	Sand/silt	1	Sand/silt	1	Sand/silt	1	Sand/silt	1
Gravel	0	Sand/gravel	1	Sand/gravel	1	Sand/gravel	1	Sand/gravel	1
Gravel-cobble	1	Gravel-cobble	0.2	Gravel-cobble	0.8	Gravel-cobble	0.8	Gravel-cobble	0.8
Cobble-boulder	1	Cobble-boulder	0.2	Cobble-boulder	0.8	Cobble-boulder	0.8	Cobble-boulder	0.8

Table 3.7. Lake sturgeon habitat models specific to Clarkboro. Y is equal to effective habitat area when x is river discharge.

Lifestage	Spawning	Fry	Juvenile	Sub adult	Adult
Model	$y = 0.0946x+12.542$	$y = -0.008x+2.913$	$y = 0.0082x-0.3837$	$y = 0.1579x+4.34$	$y = 0.1163x+7.0788$

4.0 Future Flow Predictions and the Implications for Fish Habitat

4.1 *Flow Models*

Predictive flow models were developed using both monthly and seasonal variables. Models using the seasonal covariates were eventually abandoned as they ended up being too coarse of a variable to accurately predict flows. These models are presented in Appendix E, but discussion will be restricted to the monthly predictive flow models that employed monthly covariates for the reasons described earlier (page 28).

4.11 *Monthly Flow Models and Covariates*

Predictive monthly flow models containing monthly covariates are presented in Tables 4.1-4.12. One trend is evident across all twelve monthly models. The size and significance of the intercept is orders of magnitude larger, while also having p-values much smaller than any of the covariates, regardless of the R^2 of the model.

To understand why the intercept is such a high value relative to the covariates, it is necessary to understand what the intercept represents. In linear regression, the intercept represents the value of the dependant variable when all covariates are set to zero. In this case, what the flow would be if the temperature of the basin was zero degrees, and there was no precipitation. While it is not always possible to interpret intercepts with this level of simplicity, in this case it helps to highlight how many processes might impact the river's discharge other than the climate variables chosen. While temperature and precipitation are known to have a major impact on discharge, there are other processes that play into this that may not be fully covered by this set of models. These processes could include (but are not limited to) evapo-transpiration, groundwater inputs, glacial melt, and evaporation. In developing the models, it was believed that the variables chosen would work as proxy's for these processes, but the entire variability that these processes introduce to a system may not have been fully captured by the covariates. This would result in the intercepts being inflated as they are capturing the variability that these processes would introduce.

Another reason for the inflated intercept may be explained by the time steps chosen for the covariates. Monthly was the finest resolution time step available to extract the data at, but even at this scale there is much variability that is lost when averaging out temperature and precipitation events over a month. Storm events, which are known to introduce important variability to riverine systems would be averaged over a month (Poff et al. 1997). This would cause the surge of precipitation introduced, or a sudden change in temperature to be dampened as it was averaged out. This inability to accurately incorporate fine mesoscale storm events may be another reason for the rise in intercept as the models are picking up these storm events as 'background noise' or baseline information. This baseline information is being represented in the intercept rather than having this variation partitioned out into the covariates representing climate. The models that used seasonal covariates, rather than monthly, had this same issue, lending more credibility to this explanation.

When discussing the rest of the covariates, there will be no further mention of the size of the p-value, or of the coefficient. Because the models were developed using MLR, the covariates are trying to capture and explain variation in the dependant variable not accounted for by previous covariates. Trying to interpret the size of the covariates could potentially be misleading as they may help explain more variability than the model shows, but due to multicolinearity and their placement in the maximal model, this variability may be masked by previous covariates. For this reason, only the sign of the coefficients for the rest of the covariates will be discussed.

4.111 *Spring Predictive Monthly Flow Models*

Looking at the monthly predictive flow models for the spring months (March, April, May), (Tables 4.1 to 4.3) the R^2 values range from 0.6363 in May to 0.7345 in April. All of the precipitation covariates have positive coefficients, for both the mountains and plains regions. This is demonstrating that for each precipitation event that corresponds with a covariate present in the model, this results in an increase in spring flow. The majority of the temperature covariates have negative coefficients for the spring predictive flow models. This could illustrate that as the temperature drops in the months with negative temperature coefficients, there will be a rise in spring flow. This is likely due to the fact that as temperature drops, there is more precipitation falling as snow rather than rain. This isn't true for every month. For example in May, where there is likely no snow to be falling, these negative relationships could be demonstrating that the less evaporation or evapotranspiration happening in the watershed would cause an increase in the flow in the spring. The only months in these spring models where temperature coefficients are positive are for March, April, and June. This could be that as these months warm up, this is causing an increase in snowpack and or glacial melt, which is resulting in an increase in spring flow.

Table 4.1. March monthly predictive flow model, listing the various covariates their coefficients and their significance. Variables include mountain precipitation (MP), plains precipitation (PP), and basin maximum and minimum temperatures (Bmax and Bmin) for various months. R^2 for the March monthly model is 0.6638.

	March	
covariate	coefficient	p-value
(Intercept)	4.026	<0.001
MP Feb	0.006	<0.001
MP July	0.004	<0.001
MP Sept	0.005	<0.001
MP Dec	0.005	<0.001
PP Jan	0.011	<0.001
PP Nov	0.013	<0.001
Bmax March	0.073	<0.001
Bmin May	-0.103	<0.001
Bmax Oct	-0.051	<0.001

In the April monthly predictive flow model (Table 4.2), there is not a single mountain precipitation covariate. This is unique and unexpected. Mountain precipitation was anticipated to be seen in all models, because it is assumed to have the most influence over flows in the SSR. There are still six precipitation covariates present in this model, so precipitation is still very important in determining April flows, but it is the precipitation that falls in the plains portion of the basin, and not the mountain portion that better explains the variability in April flows.

Table 4.2. April monthly predictive flow model, listing the various covariates their coefficients and their significance. Variables include plains precipitation (PP), and basin maximum, mean, and minimum temperatures (Bmax, Bmean, and Bmin) for various months. R^2 for the April monthly flow model is 0.7345.

	April	
covariate	coefficient	p-value
(Intercept)	5.894	<0.001
PP Jan	0.010	0.001
PP Feb	0.011	0.002
PP March	0.011	0.002
PP Aug	0.003	0.014
PP Nov	0.010	<0.001
PP Dec	0.009	0.001
Bmax Jan	-0.019	0.006
Bmin March	-0.036	0.003
Bmax April	0.026	0.016
Bmean May	-0.052	0.013
Bmax Sept	-0.060	<0.001
Bmax Oct	-0.037	<0.001

Table 4.3. May monthly predictive flow model, listing the various covariates their coefficients and their significance. Variables include mountain precipitation (MP), plains precipitation (PP), and basin maximum, mean, and minimum temperatures (Bmax, Bmean, and Bmin) for various months. R^2 for the May monthly flow model is 0.6363.

	May	
covariate	coefficient	p-value
(Intercept)	5.345	<0.001
MP Feb	0.004	0.033
MP May	0.002	0.011
MP Dec	0.006	<0.001
PP March	0.007	0.025
PP June	0.003	<0.001
PP Aug	0.004	<0.001
Bmean March	-0.021	0.031
Bmax April	-0.034	<0.001
Bmin June	0.086	0.001
Bmin July	-0.074	0.015
Bmax Oct	-0.033	0.002
Bmin Nov	-0.042	<0.001

4.112 *Summer Predictive Monthly Flow Models*

The three summer months are June, July and August (Tables 4.4 to 4.6). The coefficients of determination (R^2) vary from 0.6343 to 0.7259. With the summer months, it is again seen that the precipitation covariates in the models have a positive coefficient. There is one exception to this, the July predictive flow model where one covariate (March plains precipitation) has a negative coefficient. One reason for this negative coefficient might be due to an interaction between this covariate and another one that is not present in the model. This interaction could cause the unexpected negative precipitation coefficient.

Table 4.4. June monthly predictive flow model, listing the various covariates their coefficients and their significance. Variables include mountain precipitation (MP), and basin mean temperatures (Bmean) for various months. R^2 for the June monthly flow model is 0.6416.

June		
covariate	coefficient	p-value
(Intercept)	5.982	<0.001
MP Jan	0.002	0.055
MP March	0.003	0.048
MP May	0.007	<0.001
MP June	0.003	<0.001
Bmean April	-0.068	<0.001
Bmean Dec	-0.019	0.002

Table 4.5. July monthly predictive flow model, listing the various covariates their coefficients and their significance. Variables include mountain precipitation (MP), plains precipitation (PP), and basin maximum and minimum temperatures (Bmax and Bmin) for various months. R^2 for the July monthly flow model is 0.7259.

July		
covariate	coefficient	p-value
(Intercept)	7.615	<0.001
MP March	0.007	<0.001
MP April	0.004	0.002
MP Oct	0.003	0.020
PP March	-0.009	0.008
PP June	0.004	<0.001
PP July	0.006	<0.001
Bmin March	-0.024	0.014
Bmax May	-0.077	<0.001
Bmax June	-0.061	<0.001

Table 4.6. August monthly predictive flow model, listing the various covariates their coefficients and their significance. Variables include mountain precipitation (MP), plains precipitation (PP), and basin maximum and minimum temperatures (Bmax, and Bmin) for various months. R^2 for the August monthly flow model is 0.6343.

	August	
covariate	coefficient	p-value
(Intercept)	6.545	<0.001
MP March	0.003	0.020
MP July	0.003	0.003
PP July	0.005	<0.001
PP Aug	0.002	0.005
PP Dec	0.006	0.008
Bmax May	-0.052	<0.001
Bmax June	-0.052	<0.001
Bmin Aug	0.041	0.048

Every temperature covariate present in the summer predictive flow models is negative. As the temperature decreases, there is an increase in summer flows. The one exception present exists in the August predictive flow model, for the August temperature covariate. This is likely for the same reasons that the negative coefficients appeared in the spring models (decrease in evaporation/evapotranspiration as well as an increase in precipitation falling as snow rather than rain). This positive relationship is likely due to the fact that they are the same month. As temperature in the month that we are measuring flow increases, melts will increase, resulting in an increase in flows.

4.113 *Autumn Predictive Monthly Flow Models*

The autumn months are September, October, and November. The predictive flow models for these months are presented in Tables 4.7 to 4.9. These models appear to be very similar in structure to the rest of the predictive flow models. Unlike the temperature variables, the majority of the precipitation covariates have positive coefficients.

The October predictive flow model (Table 4.8) has one precipitation covariate that is negative, plains precipitation in March. Again, this could be a reflection of an interaction that is not otherwise represented in the October predictive flow model. In the November predictive flow model (Table 4.9) there are two precipitation covariates that are negative, mountain precipitation in February, and plains precipitation in October. The November model also has one positive temperature covariate, basin minimum temperature in November. This is similar to the case in the August predictive flow model. As temperature rises in November, it will cause an increase in snowmelt, resulting in a positive coefficient for this lone temperature covariate.

Table 4.7. September monthly predictive flow model, listing the various covariates their coefficients and their significance. Variables include mountain precipitation (MP), plains precipitation (PP), and basin maximum and mean temperatures (Bmax and Bmean) for various months. R^2 for the September monthly flow model is 0.7364.

	September	
covariate	coefficient	p-value
(Intercept)	5.839	<0.001
MP Aug	0.003	0.019
MP Sept	0.005	<0.001
PP July	0.004	<0.001
PP Aug	0.005	<0.001
Bmax May	-0.036	0.002
Bmean June	-0.059	<0.001

Table 4.8. October monthly predictive flow model, listing the various covariates their coefficients and their significance. Variables include mountain precipitation (MP), plains precipitation (PP), and basin minimum temperatures (Bmin) for various months. R^2 for the October monthly flow model is 0.7945.

	October	
covariate	coefficient	p-value
(Intercept)	3.767	<0.001
MP May	0.002	0.002
MP Sept	0.005	<0.001
PP March	-0.005	0.021
PP June	0.002	0.005
PP July	0.004	<0.001
PP Aug	0.005	<0.001
PP Sept	0.005	<0.001
PP Nov	0.005	0.002
PP Dec	0.004	0.025
Bmin April	-0.044	<0.001

Table 4.9. November monthly predictive flow model, listing the various covariates their coefficients and their significance. Variables include mountain precipitation (MP), plains precipitation (PP), and basin maximum and minimum temperatures (Bmax and Bmin) for various months. R^2 for the November monthly flow model is 0.6027.

November		
covariate	coefficient	p-value
(Intercept)	4.609	<0.001
MP Feb	-0.003	0.071
MP April	0.003	0.023
MP Aug	0.004	<0.001
MP Oct	0.009	<0.001
PP Feb	0.007	0.055
PP July	0.005	<0.001
PP Sept	0.002	0.069
PP Oct	-0.005	0.036
PP Dec	0.005	0.037
Bmax Sept	-0.037	0.002
Bmin Nov	0.026	0.002

4.114 *Winter Predictive Monthly Flow Models*

Winter months are defined as December, January and February. The R^2 for these monthly predictive flow models vary between 0.4606 and 0.6662. Precipitation covariates for all three monthly predictive flow models are positive except for one covariate (January mountain precipitation for the December flow model) (Tables 4.10 to 4.12). This precipitation covariate may be negative again because of an interaction that isn't represented in this model. The December predictive flow model also has two positive temperature covariates. It is also important to mention that the December monthly predictive flow model predicted flows that were significantly different than historic flows (Table 2.7). This may be why some of the covariates in this model are not following similar patterns found in the other winter flow models.

Table 4.10. December monthly predictive flow model, listing the various covariates their coefficients and their significance. Variables include mountain precipitation (MP), plains precipitation (PP), and basin maximum, mean, and minimum temperatures (Bmax, Bmean, and Bmin) for various months. R^2 for the December monthly flow model is 0.6662.

	December	
covariate	coefficient	p-value
(Intercept)	5.341	<0.001
MP Jan	-0.006	<0.001
MP April	0.007	0.057
MP June	0.002	0.012
MP Oct	0.006	<0.001
MP Nov	0.004	0.001
PP July	0.004	<0.001
PP Aug	0.005	<0.001
PP Dec	0.007	0.026
Bmax March	-0.020	0.030
Bmean May	-0.052	0.008
Bmax Sept	-0.064	<0.001
Bmax Nov	0.018	0.046
Bmin Dec	0.039	<0.001

Table 4.11. January monthly predictive flow model, listing the various covariates their coefficients and their significance. Variables include mountain precipitation (MP), plains precipitation (PP), and basin mean and minimum temperatures (Bmean, and Bmin) for various months. R^2 for the January monthly flow model is 0.4606.

January		
covariate	coefficient	p-value
(Intercept)	3.801	<0.001
MP June	0.003	0.007
MP Aug	0.003	0.032
MP Sept	0.003	0.059
MP Aug	0.006	<0.001
MP Nov	0.004	0.020
PP Feb	0.010	0.017
Bmin Jan	0.019	0.009
Bmean May	-0.071	0.004
Bmean Dec	-0.022	0.017

The predictive flow models for both January and February have entirely positive precipitation covariates. They both also have one positive temperature covariate each. In the January predictive flow model, basin minimum temperature in January is positive, and for the February predictive flow model, it is basin minimum temperature in February that is positive. As the temperature increases in the same month that the flow is being modelled, this will cause an increase in the melting of snowpack. This is being picked up by the models, and is showing up as an increase in flow.

Table 4.12. February monthly predictive flow model, listing the various covariates their coefficients and their significance. Variables include mountain precipitation (MP), plains precipitation (PP), and basin maximum and minimum temperatures (Bmax and Bmin) for various months. R^2 for the February monthly flow model is 0.5748.

	February	
covariate	coefficient	p-value
(Intercept)	4.133	<0.001
MP Jan	0.003	0.013
MP April	0.004	0.019
MP June	0.002	0.010
MP July	0.003	0.014
MP Dec	0.004	0.004
PP Aug	0.003	0.002
PP Oct	0.007	<0.001
Bmin Feb	0.052	<0.001
Bmin Sept	-0.099	<0.001
Bmax Nov	-0.018	0.023

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4.2 *Future flow scenarios and future habitat*

Future flow scenarios previously developed (Appendix C) were used with habitat models provided by WSA in order to examine the potential for change in lake sturgeon habitat based on a change in climate.

4.21 *Spawning*

Spawning typically occurs from the middle of April to early June (Cleator et al. 2010), therefore I have restricted the analysis to these months. Spawning habitat is of particular concern, as it may be the limiting habitat for species recovery.

In the SSR, there are no known spawning grounds. Clarkboro ferry is believed to have potential for spawning, hence this area was chosen for intensive study. Baseline habitat as determined by the processes outlined previously demonstrates that there is the potential for spawning to occur here based on flow regimes, and specific river characteristics. Habitat changes based on a change in climate are outlined in Tables 4.13 and 4.14.

Table 4.13. Spawning habitat present at Clarkboro ferry. It is presented in hectares. The habitat available in the baseline period (1961-1990) was calculated using historic flows and the habitat models. The three future time steps were calculated using data from GCM's in the predictive flow models, as well as the habitat models.

Time Step	April	May	June
baseline	37.86	53.23	94.91
2020's	30.80	47.95	89.53
2050's	27.45	42.96	79.53
2080's	25.08	39.62	73.77

Table 4.14. Percent change in spawning habitat availability as determined by comparing the future time steps to the baseline habitat. These results are considered representative of the SSR, and not just Clarkboro Ferry. The negative numbers indicate a loss in habitat rather than a gain.

Time Step	April	May	June
2020's	-19	-10	-6
2050's	-27	-19	-16
2080's	-34	-26	-22

Throughout all future time periods, and across all months where spawning is believed to occur, there is a decreasing amount of suitable habitat for lake sturgeon (refer to Table 4.14). As the amount of suitable spawning habitat in the SRR is currently unknown, and is still considered to be a species limiting habitat, this is important information to heed. If spawning areas are identified, it will be important to maintain flows to slow or stop the loss of spawning habitat.

4.22 *Fry*

Lake sturgeon fry are expected to be in the SSR from April to August. By the end of August, any fry will have reached a suitable size to be considered juveniles rather than fry. As such, it is these five months that were analysed for fry habitat in the SSR (Table 4.15 and 4.16).

Table 4.15. Fry habitat present (in hectares) at Clarkboro ferry. The habitat available in the baseline period (1961-1990) was calculated using historic flows and the habitat models. The three future time steps were calculated using data from GCM's in the predictive flow models, as well as the habitat models.

Time Step	April	May	June	July	Aug
baseline	0.77	0	0	0	0.20
2020's	1.37	0	0	0	0.51
2050's	1.65	0.34	0	0	0.56
2080's	2.9	0	0	0	2.9

Table 4.16. . Percent change in fry habitat availability as determined by comparing the future time steps to the baseline habitat. These results are considered representative of the SSR, and not just Clarkboro Ferry. Positive numbers represent a gain in habitat. May, June, and July are left blank as there was no baseline habitat available for comparison with future time steps.

	April	May	June	July	Aug
2020's	78				152
2050's	114				174
2080's	140				223

Baseline habitat shows that there is very little habitat for this life stage to exploit in the SSR historically. Any increase in fry habitat will be substantial due to this, both in its percent change, as well as its ecological significance. It is possible that spawning habitat is the limiting habitat, but as it is shown in Tables 4.15 and 4.16 fry habitat is non-existent for three of the five months when fry have the potential to be in the SSR. This is important to keep in mind when considering spawning habitat. Quality spawning habitat may exist in the SSR, but with no suitable habitat for fry to exploit, spawning would not be successful. For this reason, any increase in fry habitat availability could be quite significant ecologically.

4.23 *Juvenile*

Juvenile lake sturgeon are the first life stage that are present in the SSR for all twelve months of the year. Juvenile habitat present in the SSR varies throughout the year with the availability peaking in the summer months and tapering off through the rest of the year (Table 4.17 and 4.18).

Initially there is not much juvenile habitat, and this amount decreases further into the future. This is true for all months, and all future time steps (Table 4.18). Juvenile habitat declines the greatest of all the four life stages, at one point (January 2080's) the availability of habitat suitable in the SSR for juvenile fish completely disappears. The cooler months tend to see a greater decrease in habitat availability for juveniles. As juvenile lake sturgeon have much more mobility than fry, the low amount of habitat available, and its decreasing availability (while important to note) may not be as critical as the loss of spawning habitat, or the lack of fry habitat.

4.24 *Sub-adult*

Sub adult lake sturgeon are a life stage that is also present in the SSR for all twelve months of the year. Sub-adults are lake sturgeon that appear to be adults, but have not reached sexual maturity yet. As such, they may be slightly smaller than adults, but have outgrown the need for the protective spines on their scutes, resulting in habitat needs that are more flexible than the younger life stages. This flexibility means that as

Table 4.17. Juvenile habitat present at Clarkboro ferry. It is presented in hectares . The habitat available in the baseline period (1961-1990) was calculated using historic flows and the habitat models. The three future time steps were calc ulated using data from GCM's in the predictive flow models, as well as the habitat models.

Time Step	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
baseline	0.05	0.11	0.59	1.81	3.14	6.76	4.43	2.39	1.45	1.08	0.60	0.11
2020's	0.03	0.07	0.45	1.20	2.69	6.29	3.16	2.08	1.24	0.67	0.57	0.09
2050's	0.00	0.06	0.39	0.91	2.25	5.42	2.82	2.03	1.10	0.63	0.55	0.08
2080's	0.00	0.03	0.33	0.70	1.96	4.92	2.41	1.93	0.99	0.59	0.54	0.04

Table 4.18. Percent change in juvenile habitat availability as determined by co mparing the future time steps to the baseline habitat. These results are considered representative of the SSR, and not just Clarkboro Ferry. Negative numbers represent a loss in habitat.

Time Step	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
2020's	-35	-39	-25	-34	-15	-7	-29	-13	-15	-38	-5	-19
2050's	-90	-44	-35	-50	-28	-20	-36	-15	-24	-42	-8	-34
2080's	-100	-67	-44	-61	-38	-27	-46	-19	-32	-45	-10	-61

climate is predicted to change, sub-adult lake sturgeon are not expected to be as impacted as the younger life stages as they are more tolerant to changing flows (Tables 4.19 and 4.20). Sub-adult lake sturgeon to be more able adapt as their needs can be covered by a wider variety of habitats.

Comparing with the baseline habitat, there seems to be a substantial amount of habitat available for sub adults to use. Moving forward in time, this amount decreases, but less rapidly than for other life stages. The cooler months initially have less habitat than the warmer months, but the amount lost is relatively small. The warmer months have more habitat initially, and experience larger declines. This still leaves sub-adults with a substantial amount of habitat compared to other life stages in cool and warm months. Therefore, although the SSR may not be ideal habitat for spawning or younger fish, the SSR seems to provide adequate foraging and overwintering habitat for this life stage despite predicted changes in climate.

4.25 *Adult*

Adult lake sturgeon are fully grown and sexually mature. They are present in the SSR for twelve months of the year. Much like sub-adult habitat in the SSR, there is a substantial amount of baseline habitat available for adults relative to the amount available for younger life stages (Table 4.21). There is also minimal impact from the predicted changes in climate, particularly in the cooler winter months (Table 4.22). The warmer months in the middle of the year are predicted to experience a larger decline in the amount of suitable habitat for adult lake sturgeon, but as the baseline values are substantial, the declines predicted may not translate into a major issue for adult lake sturgeon in the SSR. As with sub-adults, the SSR could remain as an important foraging and overwintering habitat for adult fish.

Table 4.19. Sub adul t habitat present at Clarkboro ferry. It is presented in hectares . The habitat available in the baseline period (1961-1990) was calculated using historic flows and the habitat models. The three future time steps were calculated using data from GCM's in the predictive flow models, as well as the habitat models.

Time Step	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
baseline	12.7	13.8	23.2	46.6	72.2	141.8	97.1	57.8	39.7	32.5	23.3	13.9
2020's	12.3	13.0	20.3	34.8	63.4	132.8	72.6	51.7	35.6	24.6	22.7	13.5
2050's	11.8	12.9	19.2	29.2	55.1	116.1	66.0	50.8	33.0	23.9	22.4	13.2
2080's	11.3	12.4	9.0	25.3	49.5	106.5	58.1	48.9	30.8	23.1	22.1	12.6

Table 4.20 . Percent change in sub-adult habitat availability as determined by comparing the future time steps t o the baseline habitat. These results are considered representative of the SSR, and not just Clarkboro Ferry. Negative numbers represent a loss in habitat.

Time Step	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
2020's	-3	-6	-12	-25	-12	-6	-25	-11	-10	-24	-2	-3
2050's	-7	-6	-17	-37	-24	-18	-32	-12	-17	-27	-4	-5
2080's	-11	-10	-61	-46	-31	-25	-40	-15	-22	-29	-5	-10

Table 4.21. Adult habitat present at Clarkboro ferry. It is presented in hectares. The habitat available in the baseline period (1961-1990) was calculated using historic flows and the habitat models. The three future time steps were calculated using data from GCM's in the predictive flow models, as well as the habitat models

Time Step	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
baseline	13.2	14.0	21.0	38.2	57.1	108.3	75.4	46.5	33.1	27.8	21.1	14.1
2020's	13.0	13.4	18.8	29.5	50.6	101.7	57.4	42.0	30.1	22.0	20.6	13.8
2050's	12.6	13.4	18.0	25.4	44.5	89.4	52.5	41.3	28.2	21.5	20.4	13.6
2080's	12.2	13.0	10.5	22.5	40.4	82.3	46.7	39.9	26.6	20.9	20.2	13.2

Table 4.22. . Percent change in adult habitat availability as determined by comparing the future time steps to the baseline habitat. These results are considered representative of the SSR, and not just Clarkboro Ferry. Negative numbers represent a loss in habitat.

Time Step	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
2020's	-2	-4	-10	-23	-11	-6	-24	-10	-9	-21	-2	-2
2050's	-5	-5	-14	-33	-22	-17	-30	-11	-15	-23	-3	-4
2080's	-8	-7	-50	-41	-29	-24	-38	-14	-20	-25	-4	-7

5.0 General summary/conclusions

Lake sturgeon is a long lived species of fish that has adapted a unique life strategy. Their development favours rapid somatic growth in juveniles and delayed sexual maturity (Cleator et al. 2010). Habitat needs vary seasonally as well as being life stage dependent. Spawning grounds are typically shallow, fast moving waters over cobble or gravel. Juvenile lake sturgeon are found in shallow rivers or mouths of bays where the currents are slower, while overwintering in deep pools of their natal streams. Mature lake sturgeon are known to stay in deep pools of water, but will undertake migrations of 80 km or more to arrive at suitable spawning grounds. The need for diverse types of habitat combined with the long life cycle make lake sturgeon particularly sensitive to changes in their resident rivers.

Lake sturgeon have historically populated many river systems in North America, but have been negatively impacted by anthropogenic disturbances and no longer occupy the entirety of their historic range. COSEWIC has divided the current range of lake sturgeon into eight units, five of which contain populations that are endangered. The population of lake sturgeon that inhabit the SSR are one of the five endangered populations.

Climate change is predicted to have an effect on river flow and discharge. To investigate the potential for a change in climate to impact lake sturgeon habitat in the SSR, predictive flow models were developed using naturalized flow and historic climate data (temperature and precipitation). Monthly models were initially developed to predict flow using seasonal climate variables, but these proved to be too coarse of variables and were eventually discarded in favour of monthly climate variables. Flow models were used with output from various GCM's to see how future flows would respond to the predicted changes in climate. The resulting monthly future flow scenarios were used with lake sturgeon habitat models. The data produced from running the future flow scenarios through the habitat models allowed me to investigate the potential for climate change to impact habitat suitability for lake sturgeon in the SSR.

Overall, my research predicts that the SSR will be impacted by climate. This understanding is supported by multiple studies (Barnett, Adam, and Lettenmaier 2005; Wrona et al. 2006; Eaton and Scheller 1996). Spring and summer flows will decrease into the future, also agreeing with literature (Rood et al. 2008; Lapp et al. 2005). This is resulting in a loss of habitat in the summer months. For lake sturgeon spawning habitat, this is brought about by a decrease in the amount of suitable area for spawning, which agrees with ideas presented in Morrison et al. (2002) and Jones et al. (2013). Morrison et al. (2002) discusses how the decrease in flow can cause an increase in temperature of the water. This resulted in less successful spawning of salmon. Jones et al. (2013) points out that as climate is predicted to change, the spatial distribution of fish will contract. This is due to habitat (including spawning habitat) becoming less suitable. While a loss of spawning habitat is a loss of critical habitat, not all life stages experience a decline.

Fry habitat is predicted to increase in in the same months that spawning habitat is predicted to decrease. This disagrees with much of the literature, which predicts a decline in general habitat across all life stages (Morrison, Quick, and Foreman 2002; Mohseni, Stefan, and Eaton 2003; Eaton and Scheller 1996; Wenger et al. 2011; Rieman et al. 2007). This literature focuses mainly on thermal regimes causing the shift in habitat suitability (Mohseni, Stefan, and Eaton 2003; Morrison, Quick, and Foreman 2002; Eaton and Scheller 1996; Rieman et al. 2007; R. Jones et al. 2013; Meyer et al. 1999). Predictions show that in most cases there is an approximate 50% habitat loss by 2100 caused by increased temperatures. Papers that incorporate flow as well as water temperature also predict this same decline in habitat (Wenger et al. 2011; Morrison, Quick, and Foreman 2002). Fish populations in lakes may not see this decline though. De Stasio (1996) shows that as the temperature is predicted to increase, stratification in northern temperate lakes lasts longer resulting in increased habitat for cold and cool water fish. As lake sturgeon inhabit rivers though, the increase in fry habitat availability still does not agree with current literature. The increase in habitat available for fry may help offset some of the loss in spawning habitat. As more fry habitat is available, age-0 lake sturgeon emerge from the substrate in spawning grounds will have more available habitat in which to grow, feed, and develop into larger juveniles. Having more suitable habitat for fry may lower intra-species competition, potentially resulting in more fry successfully growing into juvenile lake sturgeon. Fry is a critical life stage, so an increase in the amount of habitat for this life stage would have a positive affect on lake sturgeon survival in the SSR.

Juvenile lake sturgeon habitat is predicted to be the most impacted by the changes in flows brought on by a change in climate. This is particularly true in the cooler winter months which see sharp decreases in habitat availability. This again agrees with much of the literature, expecting a decrease in habitat for fish (Wenger et al. 2011; Meyer et al. 1999; Rieman et al. 2007; Eaton and Scheller 1996). This steep of a decline in the amount of habitat agrees with Ruesch et al. (2012) Jones et al. (2013) and Eaton and

Scheller (1996) that there will be ~ 50% habitat loss in the future. In this study, three months in the 2080's see over 50% loss of habitat (February, April and December), and one month in the 2080's is predicted to lose all available juvenile habitat (January).

Adult and sub adult habitat remain relatively un-impacted in the cooler winter months. In the summer these life stages see a more pronounced decline in the availability of habitat in respect to the winter, but this is likely not of concern. Adult habitat, as opposed to spawning habitat, is not a limiting factor in lake sturgeon. There is also never a predicted complete loss of habitat like seen for other life stages. Similar impacts to foraging and overwintering habitat were predicted in other systems due to climate change (Jones et al. 2014). This means that even as we move forward in time, the SSR can provide important overwintering and foraging habitat for these life stages.

Knowledge gained from this study can be integrated into conservation strategies. It is known that maintaining spawning habitat is critical to any recovery plan. The predicted decline in spawning habitat seen in this study should highlight the need to protect the flows of any know spawning sites. Spawning habitat is a limiting factor in lake sturgeon survival in the SSR already. Any decline in flows, like predicted in this paper, could impact the suitability of spawning habitat. The SSR could also be managed to maintain reliable overwintering habitat. However, taking this approach would require the use of other connected systems (North Saskatchewan River, Saskatchewan River proper) to provide habitat for other life stages though. Information gained from this study, combined with information developed for other nearby systems that contain lake sturgeon populations (Bow, Oldman, Red Deer, North Saskatchewan and Saskatchewan River proper) would allow for more complete, cohesive strategies to be developed for lake sturgeon recovery.

The future status of lake sturgeon habitat is also dependant on the state of the glaciers in the headwaters of the SSR. It is known that meltwaters from the headwaters contributes the majority of the flows in the SSR, but the majority of this is from snow packs (Nazemi et al. 2013). As snow packs decline, this will become an issue as more melt will likely originate from glaciers. Source glaciers are already shrinking (Comeau, Pietroniro, and Demuth 2009), but the extent to which glacier contributions will increase into the future is not known. However, any contribution will be finite. Glacier decline is difficult to project as it is based on many different local factors such as glacier shape, size, steepness and ice depth (Cohen 1991). This uncertainty should be kept in mind, and need to be incorporated into future conservation strategies developed for lake sturgeon.

Other studies have previously investigated the potential for climate change to impact fish habitat (Ficke, Myrick, and Hansen 2007; Battin et al. 2007; Jones et al. 2014). These have mainly focused on changes in thermal regimes (Mantua, Tohver, and Hamlet 2010; Jones et al. 2014; Ficke, Myrick, and Hansen 2007; Battin et al. 2007), with only a select few looking at the potential for changes in flow regimes to impact fish habitat (van Vliet, Ludwig, and Kabat 2013; Tedesco et al. 2013). There is agreement that as climate is predicted to change, there is an overall trend to lose suitable fish habitat. This was demonstrated with bull trout (Jones et al. 2014), salmon (Mantua, Tohver, and Hamlet 2010), and in this study, lake sturgeon.

Future research could go in various directions. The predictive flow models developed could be used with habitat information for other species of fish. In unregulated systems, the natural variation in flow allows different species of fish ever changing opportunities to flourish, or in some cases only subsist or decline. Having a better understanding of how the various species of fish present in the SSR are expected to be impacted by a change in flows brought on by climate change would allow more comprehensive and robust management strategies to be developed. For example, how improvements to habitat for one species may be detrimental to the habitat of another species.

Another potential direction for future research could focus on model development. The inclusion of other parameters into the predictive flow models should be considered, such as water temperature, or day length. These variables are thought to have an impact on habitat suitability, but the extent is not known. These would help make the models more robust, and potentially explain more variation in my models. This would also provide a more comprehensive look at the relevance of various variables for predicting the suitability of fish habitat.

Finally the procedure used in my study could also be applied to other systems that have populations of lake sturgeon. This would allow a better understanding of the implications of climate change on lake sturgeon habitat availability. Systems such the North Saskatchewan River and Saskatchewan River proper are connected to the SSR, hence a set of models for the entire Saskatchewan River system may be more effective for conservation of the species. This knowledge could help develop more robust and comprehensive lake sturgeon conservation strategies.

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Appendix A

A chronological listing of the various projects in the SSRB that were taken into consideration when developing naturalized flows.

<u>1912 or earlier:</u>

The St. Mary River Irrigation District (including the Magrath, Raymond, and Taber Irrigation Districts) began diverting water from the St. Mary River near Kimball for irrigation purposes prior to 1912. These diversions entered Pinepound Creek near Woolford and were conveyed to near Spring Coulee before being again diverted to Pothole Creek and ultimately, to the district. Return flows from the SMRID enter the St. Mary River, the Oldman River, and the South Saskatchewan River.

The Western Irrigation District (WID) also began prior to 1912 with diversions from the Bow River at Calgary below the Bow Elbow River confluence. Return flows from the WID entered the Bow River upstream of the Carseland Weir and between the Carseland Weir and the Bassano Dam. Significant return flow from the WID also went to the Red Deer River via the Rosebud River.

Diversions from the Highwood River to the Little Bow River, via the Little Bow Canal, started prior to 1912.

<u>1914:</u>

The Eastern Irrigation District (EID) started diverting water from the Bow River near Bassano for major irrigation. Return flows from the EID were primarily directed to the Red Deer River with significant amounts also going to the Bow River.

<u>1917:</u>

The Cascade Power Plant, which uses Lake Minnewanka as a source of water, started operation in 1912 albeit Lake Minnewanka was significantly lower (and having a smaller surface area) than at present. Records of water level for Lake Minnewanka however were not collected until 1917. Since it was impossible to reconstruct the influence of this project for earlier years, 1917 was the first year that the effect of the Cascade Power Plant was incorporated into the natural flow calculations.

The United States of America stores water in Lake Sherbourne and diverts it from the St. Mary River to the Milk River. These diversions and the regulating effects of storage began being recorded in 1917. The records of these influences were obtained from the

Prairie Provinces Water Board (PPWB) and were included in the natural flow computation.

1918:

The Bow River Irrigation District (BRID) began diverting water from the Bow River at Carseland Weir to fill the McGregor-Travers Reservoirs. As these reservoirs had substantial storage, irrigation diversion to the district did not commence until about two years later.

1920:

Diversions from the McGregor-Travers Reservoirs to the Bow River Irrigation District started in 1920. While return flows from the BRID went primarily to the Bow River, significant returns also went to the Oldman River and to the Little Bow River.

1923:

The Lethbridge Northern Irrigation District (LNID) began operations in this year. Return flows from the LNID, which also started in this year, went to the Oldman River and to the Little Bow River above their confluence.

1924:

The United Irrigation District began diverting water from the Belly River in this year. Return flows from the UID went to both the Belly River and Waterton River.

1929:

The Ghost Lake Reservoir on the Bow River was created as a power plant reservoir.

1931:

The Mountain View, Leavitt, and Aetna Irrigation Districts began diverting water from the Belly River. Return flows from these irrigation districts went to the Belly River and the St. Mary River.

1932:

Glenmore Reservoir was constructed on the Elbow River in Calgary to provide a source of municipal water supply.

Upper Kananaskis Lake in the Kananaskis River basin was controlled to provide regulated storage of 43,000 cubic decametres of live storage. This storage was primarily used to provide a steady flow for floating logs down the Kananaskis River.

1933:

Consumptive use of water by the City of Calgary was documented from this year onward and was, therefore, incorporated into the natural flow calculations at this point in time.

1941:

The headwaters of the Ghost River were partially diverted to Lake Minnewanka to provide additional water for the Cascade Power Plant.

1942:

Records on the consumptive use of water from the Oldman River by the City of Lethbridge were available from this year onward.

Consumptive use of water by the City of Medicine Hat from the South Saskatchewan River was documented beginning in this year.

Lake Minnewanka was raised an additional 65 feet by constructing a semi-hydraulic earth fill dam on the Cascade River at the site of the 1912 dam.

Live storage in Upper Kananaskis Lake was increased to about 125,000 cubic decametres.

1947:

Barrier Reservoir on the Kananaskis River, having a live storage of about 25,000 cubic decametres, was built and was incorporated into the natural flow calculations.

1949:

The headwaters of Smith -Dorrien Creek (Mud Lake diversion) in the Kananaskis River basin were diverted to the Spray Lakes Basin.

1950:

The Spray Lakes Reservoir in the Spray River Basin was created and subsequently used as a source of water for power plants.

1951:

Diversion of water from the Spray Lakes Reservoir began by taking water from the basin and diverting it through power plants directly to the Bow River. Much of the flow, which previously went down the Spray River to the Bow River near Banff, was re-routed for power production and as a result now enters the Bow River near Canmore.

The St. Mary Reservoir was completed this year and replaced the previous upstream diversion from the St. Mary River, which supplied water to the SMRID. While diversions from the reservoir to the district began in this year, a breach in the canal resulted in significant spills into Pinepound Creek.

1952:

The McLeod Irrigation District was reported to be effective from 1952 to 1954 in the report of the Saskatchewan Nelson Basin Board (1952) and was, therefore, incorporated into the natural flow calculations using that data.

1954:

Bearspaw Reservoir on the Bow River upstream of Calgary was created as a power plant reservoir.

The Ross Creek Irrigation District was established this year and began using water from Ross Creek

1955:

Lower Kananaskis Lake on the Kananaskis River was controlled to provide 64,000 cubic decametres of live storage for hydro-electric power purposes. With the addition of the penstock and powerhouse in this year, storage in the Upper and Lower Kananaskis Lakes began being used for power production.

1959:

Diversions of water from the Belly River to the St. Mary Reservoir were made possible upon completion of the Belly River Weir and the Belly-St. Mary Diversion Canal.

1965:

Waterton Reservoir on the Waterton River was completed and water began to be impounded.

1966:

Chain Lakes Reservoir in the headwaters of Willow Creek began to impound water to augment downstream flows in the creek.

1968:

The Waterton-Belly Diversion Canal Diversion was completed and diversions from the Waterton Reservoir to the Belly River, for eventual use in the SMRID, began in this year.

1983:

Filling of Glenifer Lake on the Red Deer River began in July. It was used to regulate winter flow on the Red Deer River.

1991:

Filling of Oldman Reservoir on the Oldman River began in April. The reservoir is used to supply water to the irrigation districts in southern Alberta.

Appendix B

Pearsons correlation values of the three different temperature covariates when compared to monthly flow values. Each monthly flow was compared with the basin minimum, maximum, and mean temperature. The temperature variable with the greatest absolute correlation to flow was used in the maximal model.

		Monthly Flow Being Modelled											
		Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Basin Minimum Temp	Jan	0.17	-0.13	-0.11	-0.32	-0.08	-0.12	-0.26	-0.07	-0.14	0.02	-0.02	-0.07
	Feb	-0.08	0.43	0.03	-0.14	-0.10	-0.02	0.15	0.18	0.10	0.10	0.10	0.05
	Mar	-0.13	0.07	0.27	-0.49	-0.37	-0.21	-0.15	-0.05	-0.03	0.09	0.00	0.01
	April	-0.15	-0.05	0.07	0.06	-0.25	-0.38	-0.15	-0.04	-0.13	-0.03	-0.03	0.03
	May	-0.22	-0.09	-0.14	-0.22	0.05	-0.23	-0.28	-0.13	-0.10	-0.05	-0.06	-0.12
	June	-0.18	-0.10	-0.19	-0.13	-0.03	0.00	-0.29	-0.24	-0.27	-0.19	-0.15	-0.22
	July	0.03	-0.11	-0.11	-0.02	-0.07	-0.02	-0.05	-0.25	-0.10	-0.06	-0.05	-0.09
	Aug	-0.21	0.03	-0.10	-0.21	-0.19	0.01	0.14	0.16	-0.12	-0.18	-0.12	-0.20
	Sept	-0.17	-0.26	-0.24	-0.20	-0.06	0.04	0.00	-0.16	-0.21	-0.32	-0.34	-0.23
	Oct	0.01	-0.06	-0.10	-0.14	-0.12	0.23	0.19	0.21	0.11	0.07	0.01	-0.02
	Nov	-0.24	-0.07	-0.38	-0.23	-0.21	-0.15	-0.05	0.03	-0.01	-0.14	0.04	-0.11
	Dec	-0.28	-0.23	-0.25	-0.27	-0.07	-0.13	-0.16	-0.10	0.04	-0.02	-0.05	0.15
Basin Mean Temp	Jan	0.17	-0.12	-0.12	-0.33	-0.10	-0.13	-0.26	-0.06	-0.14	0.01	-0.02	-0.07
	Feb	-0.08	0.42	0.02	-0.16	-0.12	-0.02	0.15	0.17	0.09	0.10	0.10	0.05
	Mar	-0.13	0.08	0.30	-0.50	-0.38	-0.20	-0.12	-0.02	-0.03	0.11	0.03	0.02
	April	-0.15	-0.03	0.04	-0.03	-0.33	-0.41	-0.17	-0.03	-0.09	-0.01	0.00	0.02
	May	-0.28	-0.13	-0.14	-0.22	-0.08	-0.32	-0.35	-0.26	-0.19	-0.13	-0.11	-0.14
	June	-0.16	-0.16	-0.17	-0.14	-0.01	-0.17	-0.46	-0.37	-0.33	-0.26	-0.23	-0.27
	July	0.00	-0.19	-0.18	-0.02	-0.01	-0.02	-0.35	-0.57	-0.23	-0.22	-0.19	-0.20
	Aug	-0.26	0.02	-0.11	-0.25	-0.30	-0.07	-0.01	-0.05	-0.36	-0.35	-0.30	-0.33
	Sept	-0.21	-0.25	-0.32	-0.30	-0.11	0.02	-0.04	-0.15	-0.29	-0.47	-0.42	-0.33
	Oct	-0.09	-0.13	-0.18	-0.24	-0.17	0.17	0.11	0.14	0.06	-0.04	-0.12	-0.12
	Nov	-0.24	-0.08	-0.40	-0.26	-0.20	-0.14	-0.07	0.01	0.00	-0.14	0.01	-0.12
	Dec	-0.29	-0.22	-0.26	-0.29	-0.08	-0.13	-0.16	-0.09	0.05	-0.01	-0.04	0.14
Basin Maximum Temp	Jan	0.17	-0.12	-0.14	-0.35	-0.11	-0.14	-0.27	-0.06	-0.14	0.00	-0.03	-0.07
	Feb	-0.07	0.42	0.01	-0.20	-0.14	-0.02	0.15	0.16	0.08	0.10	0.11	0.06
	Mar	-0.10	0.09	0.31	-0.49	-0.37	-0.17	-0.09	0.00	-0.01	0.12	0.06	0.04
	April	-0.13	-0.01	0.02	-0.08	-0.35	-0.41	-0.17	-0.01	-0.05	0.01	0.03	0.03
	May	-0.27	-0.13	-0.13	-0.20	-0.13	-0.34	-0.36	-0.31	-0.22	-0.16	-0.12	-0.13
	June	-0.12	-0.17	-0.15	-0.13	0.00	-0.25	-0.51	-0.40	-0.32	-0.27	-0.24	-0.27
	July	0.00	-0.19	-0.18	-0.02	0.03	-0.01	-0.43	-0.61	-0.25	-0.26	-0.23	-0.20

Aug	-0.25	0.03	-0.11	-0.25	-0.32	-0.10	-0.08	-0.12	-0.43	-0.39	-0.35	-0.35
Sept	-0.20	-0.22	-0.33	-0.33	-0.13	0.01	-0.06	-0.14	-0.30	-0.51	-0.43	-0.35
Oct	-0.14	-0.15	-0.23	-0.28	-0.19	0.12	0.06	0.09	0.02	-0.11	-0.19	-0.18
Nov	-0.24	-0.09	-0.41	-0.30	-0.20	-0.14	-0.09	-0.01	0.00	-0.14	-0.02	-0.14
Dec	-0.28	-0.21	-0.27	-0.31	-0.09	-0.13	-0.16	-0.08	0.05	-0.01	-0.04	0.12

Appendix C

Graphs of future flow scenarios for all three time steps. The mean of all 5 future scenarios was used with the lake sturgeon habitat information.

Table C.1. Mean future flow predictions (across all five future climate scenarios) for the South Saskatchewan River over all three future time steps as well as baseline flows.

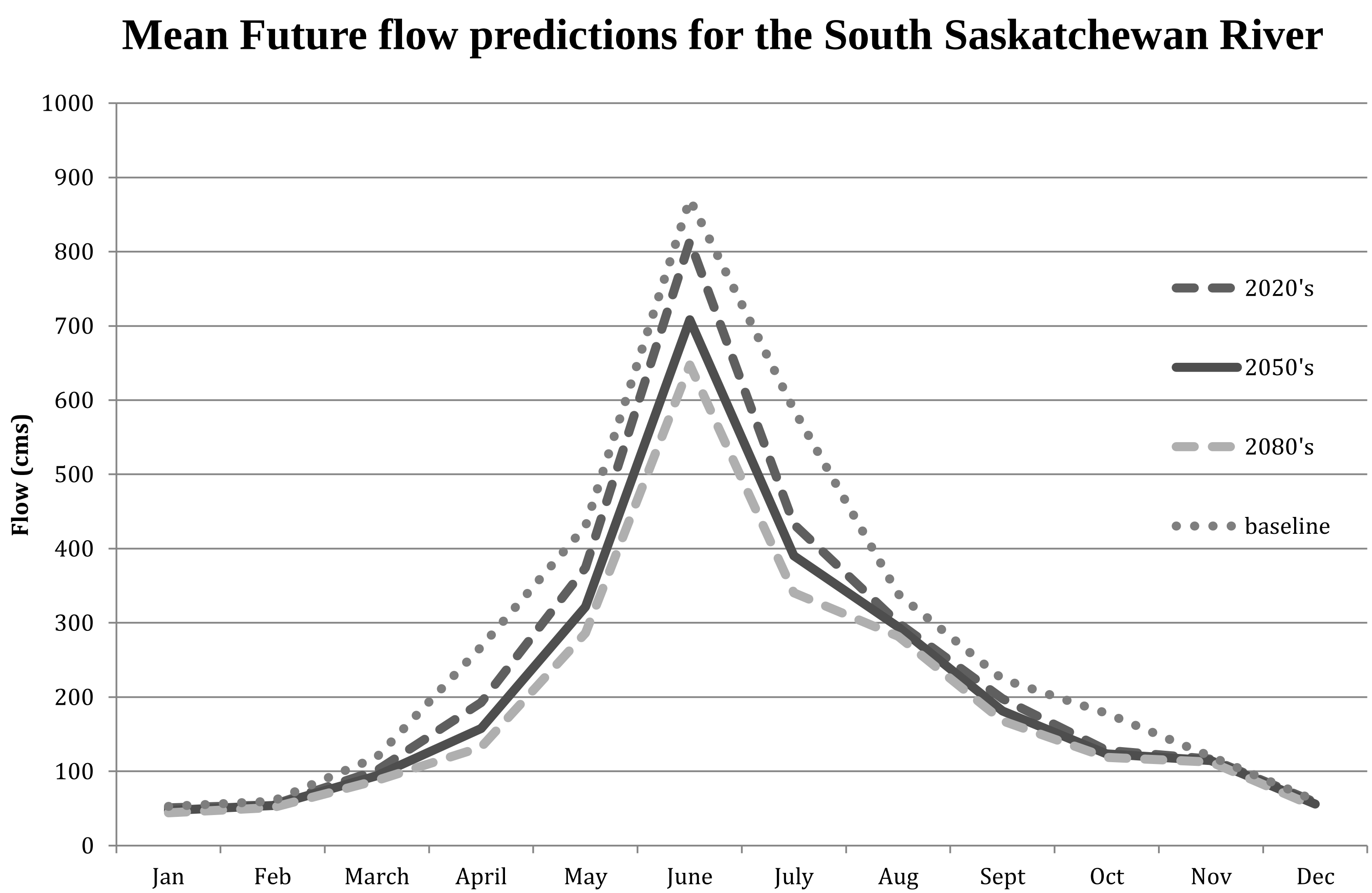


Table C.2. Future flow scenarios for the 2020's for all five of the future climates (hot, cold, wet, dry, and average futures).

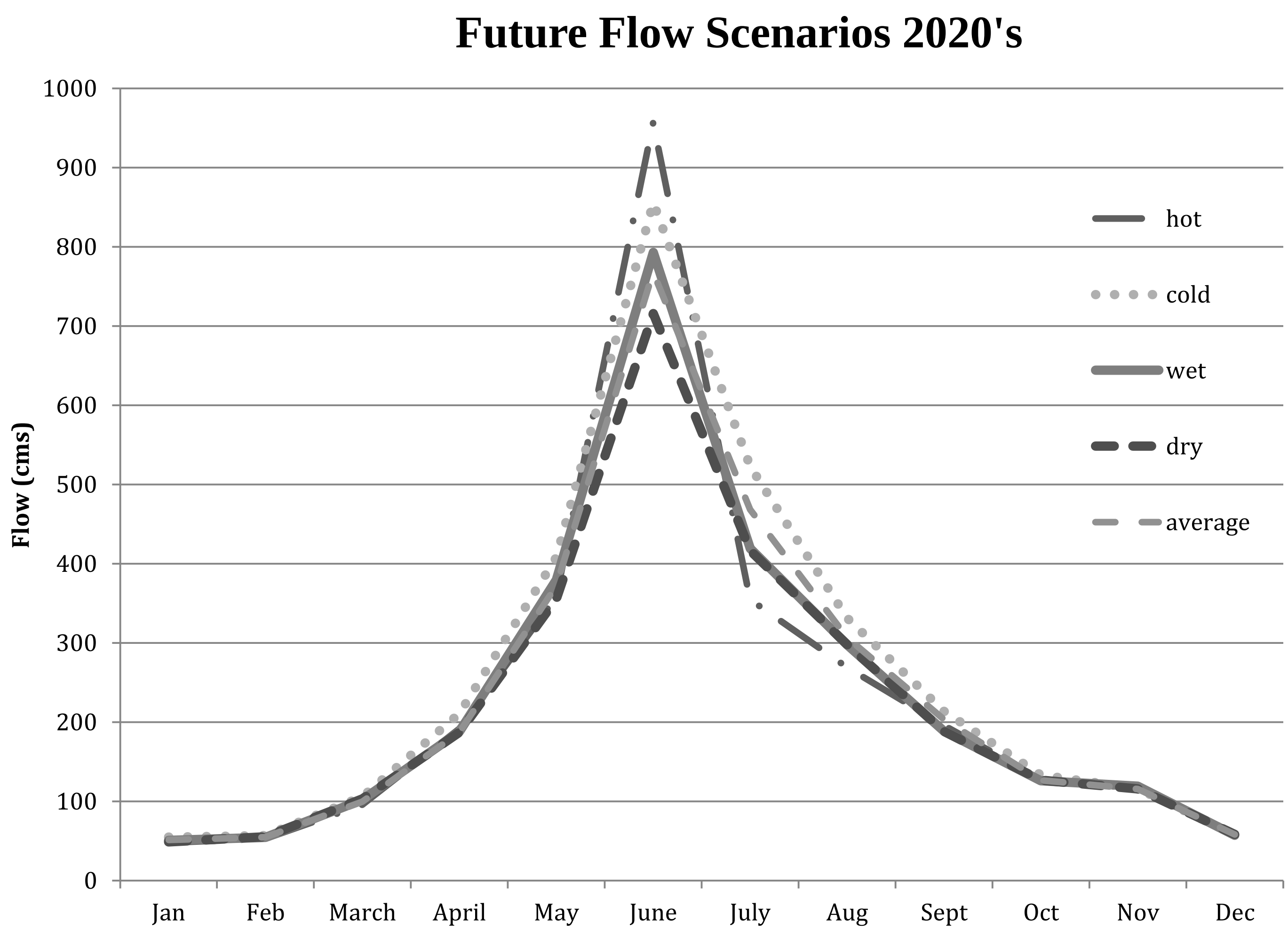


Table C.3. Future flow scenarios for the 2050's for all five of the future climates (hot, cold, wet, dry, and average futures).

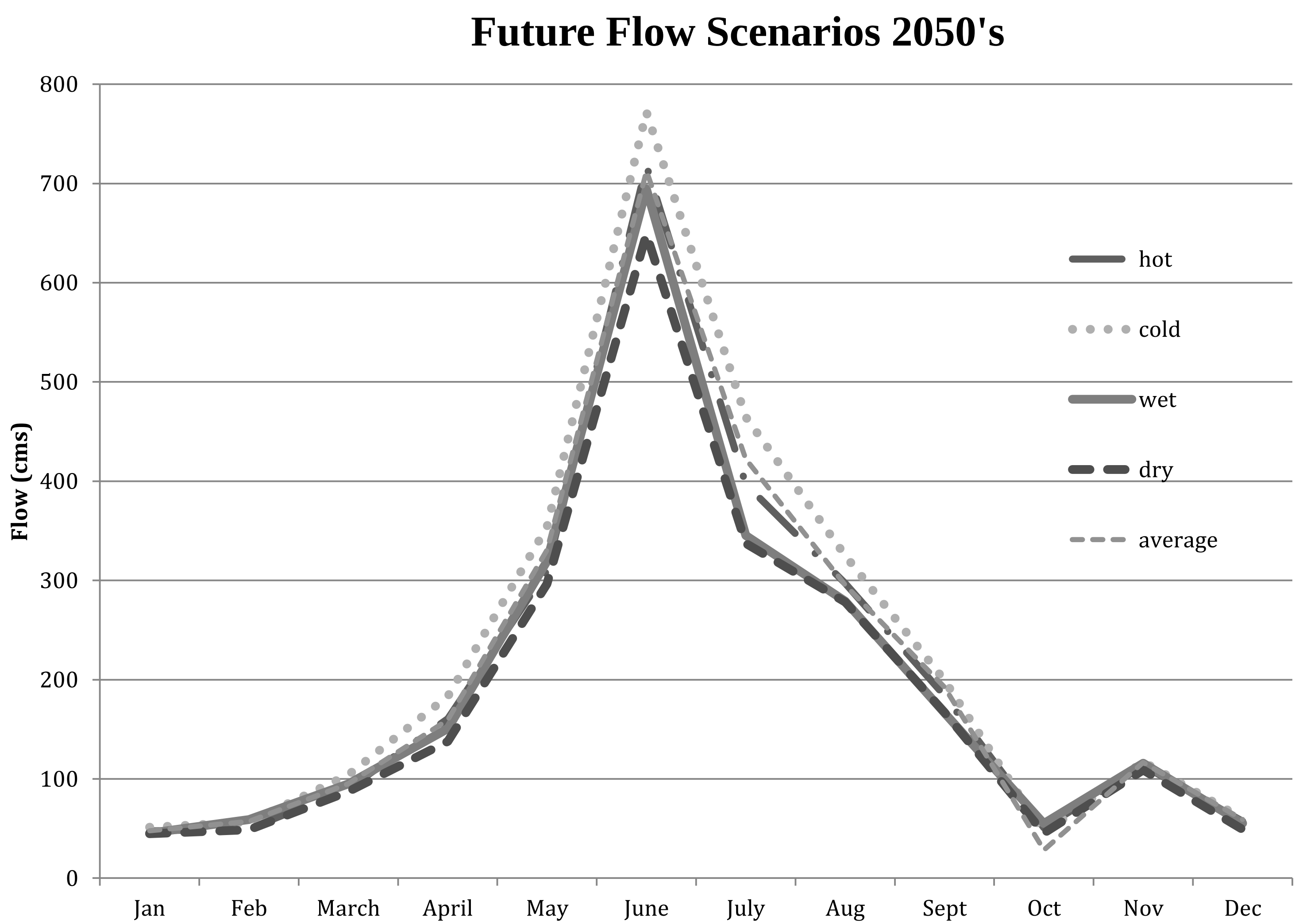
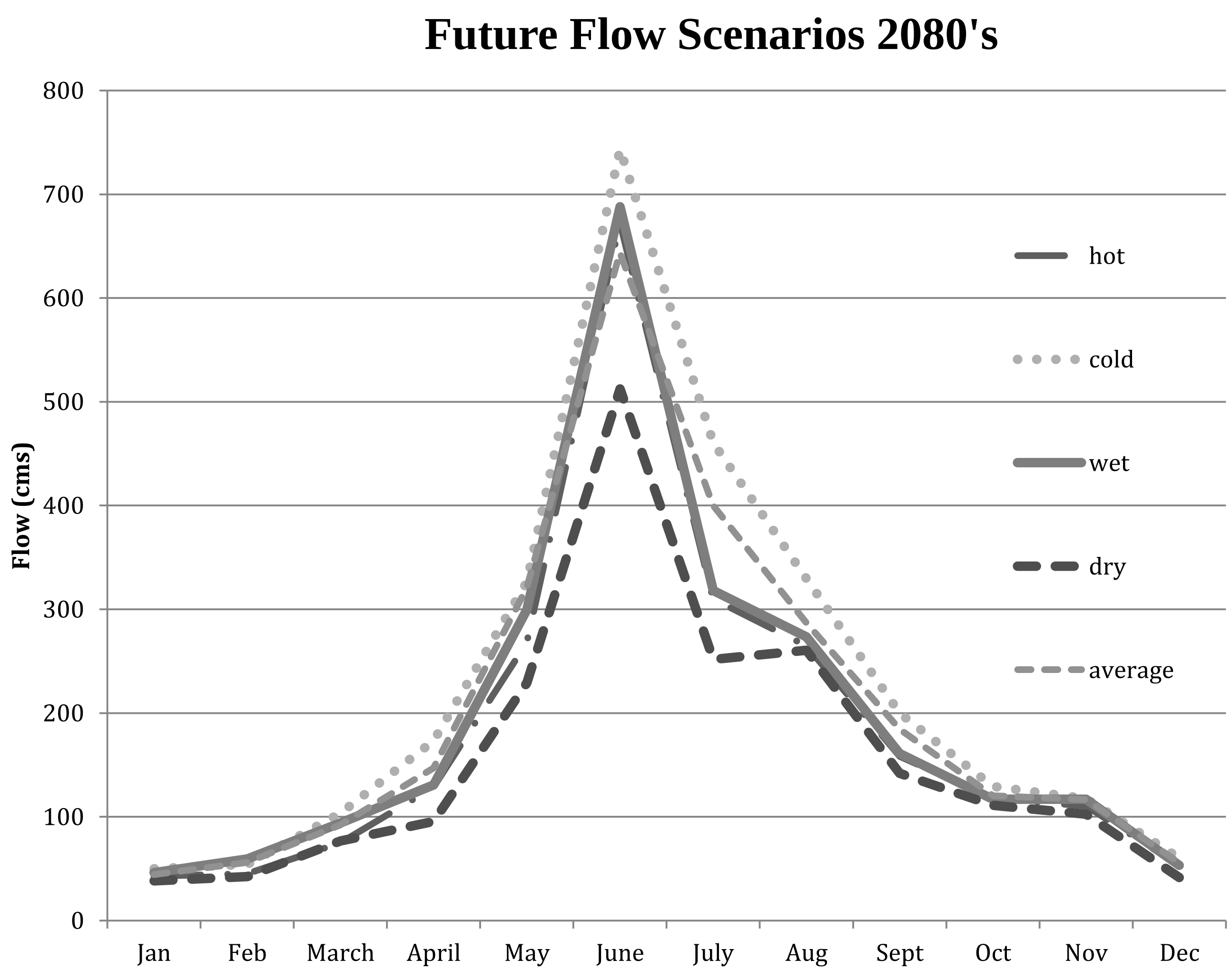


Table C.3. Future flow scenarios for the 2080's for all five of the future climates (hot, cold, wet, dry, and average futures).



Appendix D

Detailed information about the GCM's chosen for this project

Model Identity	**Model Name**	**GISS AOM 4x3**
	Institution	NASA Goddard Institute for Space Studies (GISS), USA
	Vintage	2004
Component Model Characteristics		
Atmosphere	resolution	4 degrees longitude, 3 degrees latitude
	layers	12 vertical layers
	prognostic variables	mass; eastward velocity; northward velocity; mean potential enthalpy; eastward, northward, and vertical gradients of potential enthalpy; mean water vapor; eastward, northward, and vertical gradients of water vapor (all variables are three dimensional)
Ocean	resolution	4 degrees longitude, 3 degrees latitude
	layers	16 vertical layers
	prognostic variables	mass; eastward velocity; northward velocity; mean potential enthalpy; eastward, northward, and vertical gradients of potential enthalpy; mean salt; eastward, northward, and vertical gradients of salt (all variables are three dimensional)
Sea Ice	resolution	4 degrees longitude, 3 degrees latitude
	layers	2 mass layers; 4 thermal layers; single ice thickness
	prognostic variables	horizontal sea ice cover; eastward and northward gradients of horizontal sea ice cover; snow and sea ice mass; heat content of layer; internal sea ice pressure; eastward velocity; northward velocity
Continents	resolution	4 degrees longitude, 3 degrees latitude
	layers	ground has 4 layers plus one for snow; land ice has 4 layers; liquid lake has 2 layers; lake ice treated like sea ice

Model Identity	Model Name	ECHO-G = ECHAM4 + HOPE-G
	Institution	Meteorological Institute of the University of Bonn (Germany), Institute of KMA (Korea), and Model and Data Group
	Vintage	2001
Component Model Characteristics		
Atmosphere	resolution	T30 L19
	layers	7 layers above 200 hPa, 5 layers below 850 hPa
	prognostic variables	vorticity, divergence, temperature, log surface pressure, water vapor, mixing ratio of total cloud water
Ocean	resolution	even grid rows (E/W) correspond to a T42 Gaussian grid in high and mid latitudes; towards the equator the meridional distances decrease (min = 0.5 degrees)
	layers	20 layers
	prognostic variables	potential temperature, salinity, zonal and meridional velocity, surface elevation
Sea Ice	layers	two ice thickness categories
	prognostic variables	ice volume, ice concentration, ice velocities, snow volume
Continents	resolution	same as for atmosphere
	layers	5 soil layers with one extra layer if snow is present
	prognostic variables	soil temperature, snow at the canopy, snow at the surface, liquid water at the canopy, soil water

Model Identity	Model Name	MIROC3.2 (Model for Interdisciplinary Research on Climate)
	Institution	CCSR/NIES/FRCGC, Japan; CCSR = Center for Climate System Research, University of Tokyo; NIES = National Institute for Environmental Studies; FRCGC = Frontier Research Center for Global Chance, Japan Agency for Marine-Earth Science and Technology (JAMSTEC) Marine-Earth Science and Technology (JAMSTEC)
	Vintage	2004
Component Model Characteristics		
Atmosphere	resolution	T106 L56
	layers	29 layers above 200 hPa, 10 layers below 850 hPa
	prognostic variables	temperature; northward and eastward wind components; surface pressure; specific humidity; cloud water; cloud base mass flux of cumulus convection, mineral dust, sea salt, sulfate, SO2, DMS, black carbon and organic carbon
Ocean	resolution	0.28125 degree in longitude, 0.1875 degree in latitude,
	layers	47 vertical layers
	prognostic variables	zonal and regional velocity, temperature, salinity, sea surface height
Sea Ice	resolution	0.28125 degree in longitude and 0.1875 degree in latitude
	layers	2 thickness categories
	prognostic variables	concentration, grid-mean thickness, zonal and meridional velocity
Continents	resolution	T106 2x2
	layers	5 layers for heat and water
	prognostic variables	soil temperature, soil moisture, soil ice content, canopy water storage, snow mass, snow albedo, surface and canopy skin temperature, river water storage

Model Identity	Model Name	CSIRO Mark 3.0, or CSIRO-Mk3.0
	Institution	CSIRO Australia
	Vintage	2001
Component Model Characteristics		
Atmosphere	resolution	T36 L18
	layers	5 layers above 200 hPa, 4 layers below 850 hPa
	prognostic variables	temperature, vorticity, divergence, surface pressure, atmospheric moisture (vapor, liquid, and ice)
Ocean	resolution	1.875° EW by approximately 0.84° NS
	layers	31 levels
	prognostic variables	velocities, temperature and salinity
Sea Ice	resolution	1.875° EW by approximately 1.875° NS
	layers	1 or 2 depending on ice depth
	prognostic variables	ice depth, ice temperature, snow depth snow temperature, brine heat reservoir, leads fraction, temperature of mixed layer in leads and under ice
Continents	resolution	T63
	layers	6 soil layers
	prognostic variables	surface temperature, soil temperature and water amount, if land is frozen then ice amount, moisture amount on vegetation canopy, puddle depth on land, snow layer temperatures, snow densities, total snow mass, snow age

Appendix E

Predictive flow models using seasonal variables. These models were discarded, and not used with habitat data.

January (R^2=0.3851)		
variable	coefficient	p-value
intercept	3.450281	< 2e-16
MP Summer	0.001654	0.015
MP Autumn	0.005096	1.30E-08
Bmean Spring	-0.101196	4.20E-05

Febrary (R^2=0.178)		
variable	coefficient	p-value
intercept	3.417318	< 2e-16
MP Summer	0.0015891	0.032349
MP Autumn	0.0031679	0.000546

March (R^2=0.4331)		
variable	coefficient	p-value
intercept	4.3692454	< 2e-16
MP Summer	0.0018581	0.00934
MP Autumn	0.0031943	0.0046
Bmax Autumn	-0.0700168	0.00423
PP Winter	0.0068754	0.00369

April (R^2=0.5968)		
variable	coefficient	p-value
intercept	4.8647721	< 2e-16
Bmean Spring	-0.0577043	0.01566
Bmean Autumn	-0.0557444	0.01815
PP Summer	0.0017041	0.01257
PP Autumn	0.0046951	0.00235
PP Winter	0.0152485	1.00E-09

May (R^2=0.3641)		
variable	coefficient	p-value
intercept	6.3947973	< 2e-16
MP Summer	-0.002334	0.043373
MP Autumn	0.002212	0.003305
MP Winter	0.0043901	4.75E-06
Bmean Summer	-0.0823701	1.13E-01
PP Summer	0.0029778	0.000806

June (R^2=0.4946)		
variable	coefficient	p-value
intercept	5.3704778	< 2e-16
MP Spring	0.0049595	3.55E-08
MP Winter	0.002627	0.00148
PP Spring	0.002373	0.05361
PP Autumn	0.0016319	0.07439

July (R^2=0.3208)		
variable	coefficient	p-value
intercept	6.8325841	3.57E-13
MP Spring	0.0047165	1.14E-06
MP Autumn	0.0019397	0.0239
Bmax Summer	-0.0728583	0.0268
PP Winter	0.0047719	0.0448

August (R^2=0.1891)		
variable	coefficient	p-value
intercept	5.0918526	< 2e-16
MP Spring	0.003064	0.000112
PP Summer	0.0013123	0.03383

September (R^2=0.403)		
variable	coefficient	p-value
intercept	4.7170988	< 2e-16
Bmean Spring	-0.0460386	0.0317
PP Summer	0.0047656	4.41E-11

October (R^2=0.3242)		
variable	coefficient	p-value
intercept	4.2396966	< 2e-16
PP Summer	0.0038075	9.09E-08
PP Autumn	0.0024742	0.0191

November (R^2=0.2909)		
variable	coefficient	p-value
intercept	4.0277098	< 2e-16
PP Summer	0.0034192	3.21E-07
PP Autumn	0.001911	0.0545

December (R^2=0.4878)		
variable	coefficient	p-value
intercept	3.2811189	< 2e-16
MP Autumn	0.0044862	2.93E-09
Bmean Spring	-0.0448292	0.0246
PP Summer	0.0030777	1.15E-06